SCHOOL OF CIVIL ENGINEERING

JOINT HIGHWAY RESEARCH PROJECT

JHRP-75-18

WARRANTS FOR LOCATION AND DESIGN OF LOCAL SERVICE ROADS

Carl B. Baughman

PURDUE UNIVERSITY
INDIANA STATE HIGHWAY COMMISSION

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Final Report

WARRANTS FOR LOCATION AND DESIGN OF LOCAL SERVICE ROADS

TO; J. F. McLaughlin, Director
Joint Highway Research Project

FROM; H. L. Michael, Associate Director
Joint Highway Research Project

October 1, 1975

Project: C-36-59T

File: 8-5-20

The attached Final Report by Mr. Carl B. Baughman, Graduate Instructor on our staff, is titled "Warrants for Location and Design of Local Service Roads". The JHRP Research Study for which it is made has the same title. Professor H. L. Michael provided the direction for conduct of the Study and preparation of the Report.

The Study investigated many of the problems and benefits associated with access to adjacent land from arterial highways and the use of local service roads to minimize the problems and protect the desirable flow and safety characteristics of the highway. Emphasis is placed on evaluations of design, especially at and near the intersection of the local service road and the arterial. As an example of application of the findings of the Study, a local service road system is recommended for SR 26 between I-65 and US 52 at Lafayette, Indiana. The findings will be of considerable use on other highways, especially recently constructed and future arterials.

The Report is submitted as fulfillment of the objectives of the Research Study.

Respectfully submitted,

Harold L. Michael /ms

Harold L. Michael
Associate Director

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Final Report

WARRANTS FOR LOCATION AND DESIGN OF LOCAL SERVICE ROADS

by

Carl B. Baughman
Graduate Instructor in Research

Joint Highway Research Project

Project No.: C-36-59T

File No.: 8-5-20

Prepared as Part of an Investigation

Conducted by

Joint Highway Research Project
Engineering Experiment Station
Purdue University

in cooperation with the

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Purdue University
West Lafayette, Indiana
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ABSTRACT

Baughman, Carl Bruce. M.S.C.E., Purdue University, August, 1975. Warrants for Location and Design of Local Service Roads. Major Professor: Harold L. Michael.

The purpose of this research project was to identify differences in operation and safety of highways with service road access control as opposed to direct access; to determine which traffic and geometric factors affect the operation and safety of the service road and highway at their points of intersection; and to apply these factors as criteria for the layout of various service road configurations.

Data necessary for the study was collected at eleven service road locations, as well as two direct access locations, found in seven Indiana cities. A total of 51 service road and highway intersections, classified into various types, were studied at these locations. The kinds of data required for the analysis were conflicts data, volume data, accident data, speed data, and questionnaire data.

Analysis of a conflicts index developed from conflict and volume data was not reliable, but it is considered important that no conflicts were recorded on approaches of service roads terminating at a crossroad. Accident data was utilized to detect patterns of hazardous movements at both service road and highway intersections. A comparison of speed characteristics for five pairs of locations revealed little difference in speeds on service road highways versus direct access highways. The questionnaire responses indicated that establishments on service roads fare just as well, if not better, than those with direct access.

For seven of the intersection types studied, regression analysis was used to determine those variables which best explained the conflicts index. For instance, the volume of traffic on the service road gave a reliable explanation of conflicts at three-legged service road connections to the highway. Evaluation of the range of operational experience at such intersections indicated a maximum service road volume of about 2000

vehicles per day for acceptable operation. In a similar manner the recommendation was made to prohibit four-legged service road intersections unless the expected service road volume is less than 400 vehicles per day. Finally, those three-legged service road intersections at a crossroad which require a left turn off the crossroad when entering from the highway should not be permitted where the expected crossroad volume exceeds 500 vehicles per day; where a right-turn entry is made this crossroad volume would be about 2000 vehicles per day.

INTRODUCTION

Roadside development along major arterial highways near urban areas has advanced to the point where in many locations a "general deterioration of the traffic-carrying capability" (46)* has been observed. This impairment of the ability of the arterial to move traffic arises in large part out of the interference and absorption into the traffic stream of vehicles encroaching from a multitude of roadside access points.

In addition, those vehicles leaving the highway give rise to hazardous speed differentials, creating conflicts with the high speeds desired by arterial traffic. This problem is especially severe where access points are so closely spaced that deceleration must be executed on the traveled way.

A principal means of protecting the flow of traffic on such major highways is the provision of service roads, thereby physically separating the lanes of the highway serving high-speed through traffic from the lanes devoted to slower local traffic and access to roadside land (46). With such design, access points can be properly spaced to allow deceleration to be accomplished safely in separate lanes.

Fortunately, large developers have become increasingly aware of the advantages of limiting access to a few high-type driveways. They have recognized that the continued traffic-carrying capability and safety characteristics of the arterial streets are essential to the long-run success of their business (59). In contrast, strip commercial development, continually desirous of unlimited access to the roadside, has too often brought about traffic congestion and dangerous speed differentials due to frequent turning movements in and out of the several driveways, eventually resulting in a facility which effectively serves

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*The numbers in parentheses refer to numbers in the bibliography.

neither the through traffic nor the local establishments. In some cases of this nature, entirely new bypasses are required to serve the through traffic, thus completing the expensive process of obsolescence of the original highway.

A principal underlying condition behind this obsolescence is the subdivision of frontage property for reasons of continuing development. Administrative control over the granting of driveways is currently attempted at such locations, but the absence of any plan for providing access and the proliferation of small frontage parcels often results in many undesirable access drives even with the best intentions of local officials. Service drives appear to hold promise as a means of providing access to frontage parcels while yet protecting the movement and safety of arterial traffic and thus the public investment in the highway.

Local service roads have been used only sporadically in modern highway design, perhaps due to uncertainty of justification, but also due to confusion about proper design and operation for certain common situations. An especially crucial area of concern is the design and operation of access serving both directions of traffic on the arterial. Being adjacent to the highway as they are, intersections involving service roads may be subject to some congestion and conflict if not installed properly. Additional knowledge of local service road (LSR) design and operation would facilitate the use of this most valuable technique.

LITERATURE REVIEW

Very few research studies have dealt directly with service road design and operation, but several investigations have considered factors related to this form of access control.

Access Control

The value of access control on our major highways has become clearly evident and widely accepted since the advent of the Interstate System and urban freeways. In recent years the partial control of access has also become widely practiced, although its record of safety and service is not as outstanding as the fully-controlled Interstate System (40,42). A major reason is that considerable marginal friction, defined as the impedance that a traffic stream encounters along the perimeter of the highway (60), continues to exist from local streets and approved driveways.

On partially controlled access highways where left-turn bays eliminate the hazard of this movement, the right turn entry into a driveway with no deceleration lane was found to be the movement presenting the greatest impedance to through traffic (31).

A study by Wolfe (63) found that about 25 percent of the turns into several types of establishments (restaurants, snack bars, residences, commercial, motels) caused some interference to highway traffic, while for service station drives the proportion was 15 percent. He also indicated that about one and one-half as many accidents can be attributed to street intersections as compared to roadside driveways.

Development patterns suggested to eliminate such marginal interference points, at least in residential areas, include rear alleys, back-on development, cul-de-sacs, and service roads to intercept driveways and local streets (38). In commercial areas, attempts have been made to reduce the conflicts arising from ingress and egress by specifying minimum distances between driveways (62). Only the service road technique, how-

ever, allows the flexibility of full development along the roadside, whatever form it may take, while providing relatively uninterrupted flow for through traffic.

The legal authority to implement local service road access control is derived from the regulatory police power of the State. The access rights associated with roadside property may be limited where the public convenience and safety is at stake (14), such as where through traffic requires protection from marginal interference. Even though some circuitry of travel may become necessary to reach the property, and traffic has been diverted from the immediate frontage, the service road constitutes sufficient access to avoid compensation (16). Of course, where additional right-of-way is required to construct a service road for existing development, compensation under eminent domain is the rule (46). For new and future development, the service road is the responsibility of the developer.

Types of Service Roads

A service road has been defined as an auxiliary road that parallels a major traffic facility such as an arterial or a freeway for the purpose of providing service and access to abutting properties (40). The service road concept was evolved for the purpose of separating the access function from the movement function by inserting a buffer roadway alonside the arterial.

Different types of service roads have been recognized as serving different functions. "The minor residential service road is basically an access street for individual small lots. The service road adjacent to commercial frontage and multi-family development is primarily a collector street - an intermediate facility inserted between the traffic function of the arterial and the access function performed by the driveway" (40). The highest type of service road, often referred to as a frontage road, serves as a collector and distributor for traffic on the freeway which it parallels. This study is concerned with the first two types of service roads, which generally are two-way facilities.

The functions of these two types, in addition to the control of access and provision of local service mentioned already, include allow-

ing traffic circulation on each side of the arterial, providing additional capacity during peak hours, and possibly acting as a detour during construction and emergency operations. It has also been suggested that a service road can "accomodate parking and unparking, deceleration and acceleration, merging and weaving, and all other marginal frictions without interfering with through traffic movements" (40).

Advantages and Disadvantages of Service Roads

It is clear that service roads, when properly provided, have the potential to considerably improve the quality and safety of traffic flow for the highway corridor. Only one study of their operational effects could be found, this an investigation of the safety of service road access control conducted by the Los Angeles County Road Department. The study indicated that the "accident ratio comparing service road protection with uncontrolled access is 1 to 6; the injury accident ratio is 1 to 12" (39).

The service road access control device is an especially practical administrative tool. "The public agency exercises full control over the service road and all its openings into the arterial highway. It is less concerned with the number and location of driveways, the location of fronting properties, or the conditions of parking that prevail" (40).

Other advantages recognized include the elimination of driveways from the major street, separation of access traffic from through traffic, reduction in marginal parking friction, elimination of the hazards associated with children playing or riding bicycles in the street, and reduction of the number of highway crossings (39). In addition, service roads offer many aesthetic advantages such as the opportunity for effective highway landscaping, an impression of spaciousness, and improved driver visibility. But most importantly, service roads "not only provide more favorable access for commercial and residential development than the faster moving arterial street, but also help preserve the safety and capacity of the latter" (3).

With all of their advantages, service roads also present some disadvantages which must be taken into consideration. Certainly a major drawback is the additional land required by the service road,

amounting to a considerable cost and possible loss of property tax revenue. However, the additional expense incurred in the provision of the service road should in the long run represent a worthwhile investment through fewer accidents and continued utility of the highway.

The most serious problem of service roads concerns the design and operation of the complex at-grade multi-legged intersection which results if the service road enters the cross street near its junction with the arterial. This problem is especially complex where the intersection has two-way service roads passing through the cross road on both sides of the arterial. The resulting eight-legged intersection has a total of fifty-six different combinations of entering and leaving movements, creating sixty points of possible conflict as shown in Figure 1 (39).

Traffic signal control at such intersections has proven ineffective due to the limiting of intersection capacity which results from attempts to control the several movements. A related problem is the extreme perimeter of visibility required of drivers approaching from parallel legs, and the associated confusion of the movement of vehicles in the intersection.

Service Road Design Criteria

Efforts to establish criteria for the layout and design of service roads have simply taken the form of the suggestion of various design schemes. Mark's work is probably the most significant, especially in the area of the intersection problem. He suggests modifications such as the island bulb design, channelized exit control, cross street median, mid-block entrance and exit, and the diverted or flared service road (39). Unfortunately, disadvantages exist for each of these designs.

Very little information has been developed relating when traffic flow or locational characteristics warrant specific layouts. A search of the literature did, however, indicate the following elements of service road design:

1. one-way versus two-way operation
2. the number of and distance between access points
3. coordination of access points with median openings
4. the width of outer separation

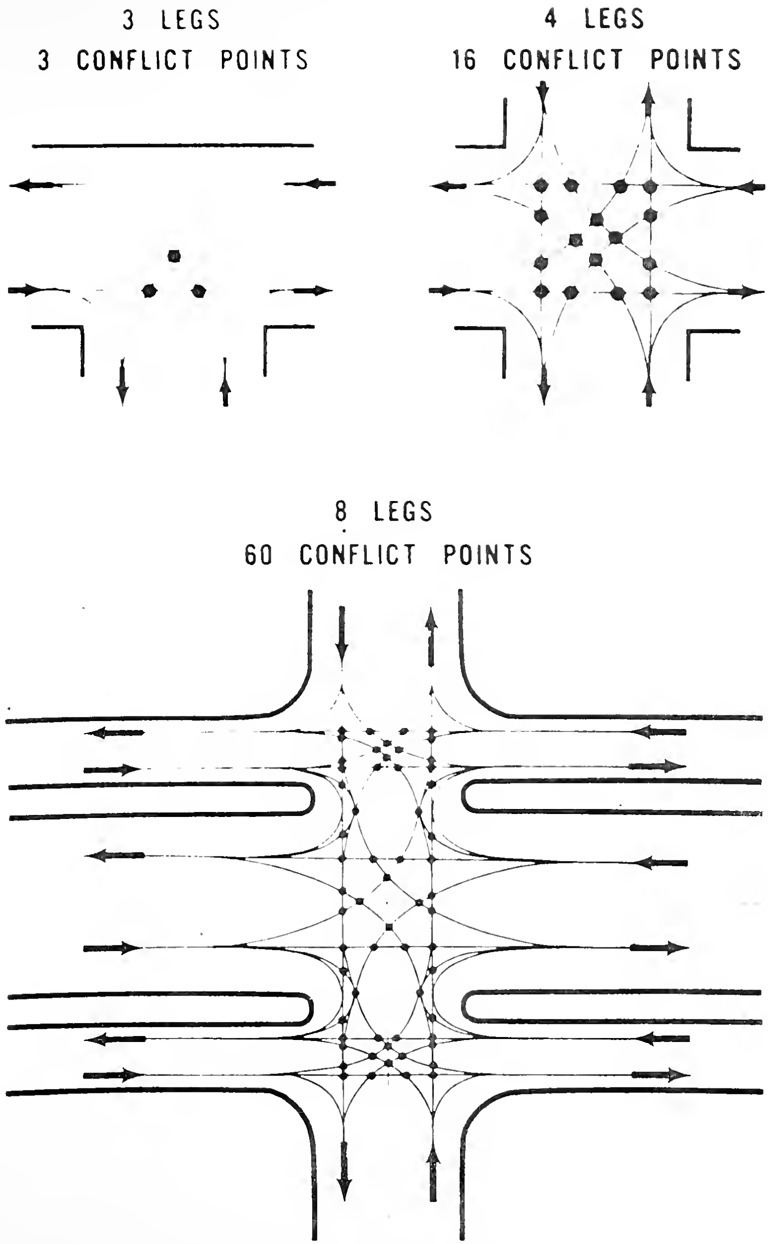


Figure 1. Traffic Conflict Points at Intersections

5. access point design
6. the width of the service road.

Suggestions found for the treatment of these elements will now be discussed.

One-way versus Two-way Operation

Discussion on this matter was found in four references (3,39,41,59), one of which tied it to the related question of providing the service road on one side or both sides of the arterial. In general, it was agreed that one-way operation brings about a reduction in vehicular and pedestrian conflicts, while also causing additional inconvenience and possible wrong-way movements. Conditions indicating one-way operation are service road continuity and their use on both sides of the arterial. Two-way service roads are suggested for location on one side, where they are discontinuous (from 300 feet (44) to ¼ mile has been suggested), or where access points to the arterial are at greater than one mile intervals (59).

The Number of and Distance between Access Points

An excellent theoretical investigation on the number of and distance between access points by Major and Buckley (36) recommends the minimum separation of entry points by about one and one-half times the acceleration distance for safe entry conditions into one lane of randomized flow. They also noted that two distant entry points will provide a greater total absorption capacity than single or closely adjacent entry points.

Another report (59) suggests that if more than six access points of intermediate driveway volumes (between 50 and 500 vehicles per day) exist on a mile of rural secondary arterial, access to individual properties should be via a service road. Driveways of over 500 vehicles per day might have direct access to such roads, but for rural primary arterials a service road is recommended for all access.

Coordination of Access Points with Median Openings

The Committee on Driveway Design and Location of the Institute of Traffic Engineers suggests that "in an urban area with frequent intersec-

tions and parallel streets or service roads, satisfactory access may be available with only minimal amounts of out-of-way travel when driveways have left turn access blocked" (31). They also indicate that left-turn bay design automatically establishes a minimum spacing between median openings. Other suggestions for minimum distances between median openings include 400 feet (Indiana), 500 feet (59), and 600 feet (48). Also, a minimum median width of 30 feet is recommended as "sufficient to allow crossing traffic to cross one roadway of a multi-lane divided highway at a time" (59).

The Width of Outer Separation

This quantity is measured between the traveled way of a roadway for through traffic and a service road or street (3). It "includes the shoulder of the through road, bus loading zones, and acceleration and deceleration lanes, as well as the curb width" (41). For two-way service roads, the outer separation should be sufficiently wide to minimize the effects of approaching traffic, especially at night when headlight glare is a nuisance. The American Association of State Highway Officials (AASHO) recommends a separation of at least 24 feet, with 40 feet being preferred (3). Other factors helping to establish the separation width include topography, ditch depth requirements, and the grade of the access opening (29,31).

The width of the outer separation becomes an especially critical design element at crossroad intersections and other access points, where it is sometimes called the distance to the radius return. Where the service road terminates in a right-angle intersection at the arterial, the Illinois Department of Transportation recommends a distance of 100 feet from the edge of the traveled way to the point of curvature (29). Where a two-way service road intersects a crossroad, widths of outer separation ranging from 39 feet to 150 feet have been considered acceptable, depending on the design vehicle and the amount of lane encroachment permitted (3,39). The AASHO dimension of 150 feet is derived on the basis of the following considerations:

1. It is about the minimum acceptable length needed for placing signs and other traffic control devices to give proper direction

to traffic on the cross street.

2. It usually affords acceptable storage space on the cross street in advance of the main intersection to avoid blocking the service road.
3. It enables turning movements to be made from the main lanes onto the service roads without seriously disrupting the orderly movement of traffic.
4. It facilitates U-turns between the main lanes and the two-way service road. (Such a maneuver is geometrically possible with a somewhat narrower separation but is extremely difficult with commercial vehicles.)

". . . Narrower separations are acceptable where service road traffic is very light, where service roads operate one-way only, or where some movements can be prohibited" (3). Another report (59) relates the separation width to the speed of the cross street, for instance suggesting 270 feet of separation for 30 miles per hour.

Access Point Design

Access point design may take basically three forms, the ordinary two-way driveway, the low-angle one-way ramp, or directional channelization. One of the latter form, called the buttonhook design, accommodates only right-turn entry and/or exit movements, and lends itself efficiently to a street or major driveway leading across the service road to a development site (40). The low-angle one-way ramps are suggested by Marks for the midblock entrance and exit configuration (39). The radii of the ordinary two-way opening depend of course on speed and vehicle requirements, but with regard to the width of such openings, Oklahoma recommends no more than 50 feet when opening into the service road.

The Width of the Service Road

The width of the service road is primarily determined by three factors--whether operation is one-way or two-way, whether or not parking is permitted, and the character of service. Paisley suggests "lane widths of 12 feet in industrial districts, 11 feet in principal business dis-

tricts, and 10 feet in residential districts" (51) as adequate. Minimum AASHO recommendations for two-way service roads with parking are two parking lanes of 8 feet plus two travel lanes of 10 feet for a minimum of 36 feet. Another element of cross section design, curb treatment, was discussed in only one reference, with several alternatives suggested, but as a minimum the provision of a curb along the property edge (59).

PURPOSE

As is evident from the literature review, considerable variability of design criteria exists in the field of service road design. Also, little quantitative information is available regarding when to use any particular configuration of access to the service road. In fact, little is known about how service road access control actually operates in practice, hence the purpose of this research is to:

1. identify and describe the differences in operation and safety of roadside locations with service road access control as opposed to direct access
2. determine the various factors that affect the operation of the service road and the highway, especially at their points of intersection
3. apply these factors as design criteria to indicate the desirability of various configurations.

DATA COLLECTION

Before describing the procedures used in collecting and analyzing the data, the definition of several terms used throughout the paper is in order. These are as follows:

Local Service Road (LSR) - an auxiliary road that parallels a major traffic facility for the purpose of providing service to abutting properties and for control of access (19,40).

Highway - a major traffic facility, generally either a major or minor arterial, which may be paralleled by a local service road.

Crossroad - a road or drive which crosses and thereby intersects with both the highway and its local service road.

Outer Separation - the area between the traveled way of a highway and a local service road. (3)

Conflict - a traffic situation in which a driver takes evasive action as evidenced by braking or weaving to avoid what he believes to be a dangerous situation.

Selection of Study Locations

The initial step was the discovery and selection of study locations. Since considerable variability exists among service road locations, the following set of criteria was developed to assure some uniformity among the locations selected:

1. Service road easily visible from highway
2. Posted maximum speed limit of highway at least 40 miles per hour (mph)
3. Length of service road at least 300 feet (44)
4. Fairly well-developed frontage on LSR and in the general area.

It should be pointed out that grade-separated locations were not of interest, as this research was directed toward the problem of the complex, multi-legged at-grade intersection.

In order to learn where service road locations could be found, interviews were held with various state and local traffic officials, followed by on-the-site inspections. Design plans and airphotos were secured where possible in order to learn more about the details of the layout and the surrounding land use.

For the conduct of additional speed studies and case comparisons, another set of criteria was developed to select sites without service roads as follows:

1. Speed limit the same as for sites with LSR
2. Similar land use and degree of development, except that sites had several direct driveways instead of LSR access control
3. Similar volumes of roadside trip generation as well as on the highway

For all speed study sites, the location had to be removed from the influence of a traffic signal for both sites with and without LSR.

Various types of land use among the different sites were desirable. Locations selected ranged from residential to commercial and even industrial, and generally tended to be along urban area bypasses or extensions of urban arterial highways. Another characteristic of the various sites was the lane design of the highway, two-lane roads or preferably four-lane roads with median. It is believed that the sample of LSR locations included in this study represents a considerable portion of all such locations in Indiana, as only a very few known sites were not included in the study.

As a means of describing the geometric and land use characteristics of each of the LSR locations, an inventory sheet was devised, a copy of which appears in Appendix A. Data were collected for both the highway and its LSR. With the information collected from the inventory sheets, design plans, and airphotos, the site layouts were drawn, which appear in Appendix B.

Conflicts Count and Volume Data

As a means of describing the operation of traffic at the various intersections which form access points between the highway and its LSR, the Traffic Conflicts Technique (TCT) developed by the General Motors Research Laboratories (52) was used. The data collected from this

method consists of both conflicts data and a volume count for the various movements at the intersection.

The TCT survey was conducted over a ten-hour day on any of three typical weekdays, Tuesday, Wednesday, and Thursday. A counting period, which lasted for one hour, began with fifteen minutes of observation on one approach, then a fifteen minute interval for recording and change of location to the opposite approach, where the cycle was repeated. For each approach two types of data were recorded, one being the conflicts count and the other the volume data (see Appendix A). The conflicts count was primarily concerned with traffic maneuvers into or out of the driveways or access points of interest. These maneuvers gave rise to the conflicts, which were indicated by vehicles on the observed approach. The volume of vehicles on the approach and their turning patterns were also counted. At intersections on the local service road, counts were made on crossroad approaches as well as the service road approaches; also counted were highway approaches at LSR access points.

The position of observation for the survey team was about 100 to 300 feet in advance of the intersection on the right side of the approach leg of interest. A third type of data used with the TCT was collected on a "Counter's Inventory Sheet of Existing Highway Features", one of which was used on each approach to record developmental, geometric, and traffic control characteristics of the intersection. A listing of the individual intersections at which conflicts counts were made is shown in Table 1.

In addition to conflicts and volume counts at intersections, which provided a twenty-five percent sample of intersection movements between 7:30-12:00 a.m. and 12:45-6:15 p.m., some twenty-four hour volume counts were taken. These were made with pneumatic tubes on sections of service roads between access points so as to obtain an estimate of the usage of each LSR on a typical day. In some cases a twenty-four hour count was made on a crossroad approach as well, giving a better understanding of traffic circulation in the service road area. Attempts to use pneumatic tubes at access openings proved unsuccessful in all but one case. All volumes were adjusted to an Average Annual Daily Traffic (AADT) volume by the use of "1974 Suburban Monthly" conversion factors provided by the Indiana State Highway Commission.

Table 1. Listing of Intersections Where Conflicts Data Was Collected

Identification No.	Intersection Type* LSR	Intersection Type* Highway	Highway No. and City	Location of Access Opening
01	A	-	US 52 Bypass, West Lafayette	University Square, 500 W
02	B	E	SR 431, Indianapolis	Madison Court, 5140 S
03	B	G	SR 431, Indianapolis	Heidenreich Floral Shop, 5320 S
04	B	E	SR 431, Indianapolis	Perry Twp. Fire Station, 5410 S
05	-	H	SR 431, Indianapolis	Northern Terminus of LSR, 5050 S
06	A	G	US 136, Speedway	5240 W
07	D	F	US 136, Speedway	Gerrard Street, 5220 W
08	B	G	US 30 Bypass, Fort Wayne	Stoller Building, 909 N
09	A	G	US 30 Bypass, Fort Wayne	Village Pools, 717 N
10	B	E	US 30 Bypass, Fort Wayne	Crossover at Lake-side G. C., 750 N
11	A	E	US 30 Bypass, Fort Wayne	Crossover at 1000 N
12	B	E	US 31 Bypass, Kokomo	Savoy Drive, 1220 S
13E 13W	D A	H -	US 31 Bypass, Kokomo	Mayfair Drive, 3120 S
14E 14W	D D	H H	US 31 Bypass, Kokomo	Terrace Drive, 3000 S
15	A	G	US 31 Bypass, Kokomo	Saratoga Drive, 1520 S
16	A	E	US 460, Clarksville	Clark Blvd. access point, 630 N
17	-	I	US 460, Clarksville	Clark Blvd. entrance, 500 N
18	B	G	US 460, Evansville	New York Ave., 1050 E

*for illustration see Figures 2 and 3.

Table 1., cont.

Identification No.	Intersection Type LSR	Intersection Type Highway	Highway No. and City	Location of Access Opening
19	D	-	US 460, Evansville	Kentucky Ave., 1000 E
20	B	E	SR 431, Indianapolis	Loretta Drive, 6600 S
21	B	E	SR 431, Indianapolis	Maynard Drive, 6700 S
22	D	H	SR 431, Indianapolis	Tulip Drive, 6830 S
23	D	H	SR 431, Indianapolis	Winchester Drive, 8100 S
24	B	E	SR 431, Indianapolis	Southview Drive, 6800 S
25	D	-	SR 431, Indianapolis	Banta Road 6500 S
26	D	F	West Tenth St., Indianapolis	Bauman Road, 6700 W
27	B	F	West Tenth St., Indianapolis	Chapel Hill Road, 7000 W
28	-	F	West Tenth St., Indianapolis	LSR Terminus, 7107 W

Accident Data

An examination of the accident history at LSR locations was considered to be of primary value in this study, thus the accident experience of the several sites was investigated. Although it was recognized that a three-year history of accidents gives reliable data (43), the use of a four and one-half year period, from January 1970 through June 1974, was considered appropriate for this study due to the low accident frequency of many service road intersections. Unfortunately, the entire four and one-half year experience was not available at all locations. Where this was the case, the extent of the accident history will be noted.

It is the accident pattern and not so much the rate of accidents that was desired for analysis. As in the conflicts study, only those collisions involving vehicles using the access points of interest were noted; other accidents such as some rear-end collisions at a traffic signal on the highway or right-angle collisions at a drive on the other side of the highway, were not considered.

A standard collision diagram was used for recording the accidents. Access to accident files and the Indiana State Police accident report form was granted by the traffic and law enforcement agencies in the jurisdictions studied. Data items recorded on the diagram (see Appendix A) included type and severity of accident, time of day, day of week, month of year, and condition of pavement. A sketch of the intersection and the pattern of collisions were then drawn.

In addition to the accident experience at the service road locations, two locations without service roads were examined for their accident history so as to provide case comparisons. Both of these sites were among the non-LSR sites used for the speed comparisons, one being a four-lane highway with median, the other a two-lane highway.

Speed Data

For the purpose of determining the effect of service road access control as compared to direct driveways on the speed of highway vehicles, speed samples were collected at five pairs of locations whose criteria were defined in the section on "Selection of Study Locations". The sam-

ple size was determined by applying the statistical formula $n = K^2\sigma^2/e^2$, where

K = the number of standard deviations referring to the desired confidence level

σ = standard deviation of the distribution

e = limits of tolerable error

n = sample size

For the purpose of this study a 95% confidence level was adopted giving $K = 1.96$. Also a standard deviation of $\sigma = 6$ mph was selected, giving a slightly more conservative result than the 5 mph suggested as typical by Pignataro (53). Finally, a tolerable error of $e = \pm 1.0$ mph was used, giving $n = 138$ vehicles. No distinction between truck speeds and passenger vehicle speeds was required, as the composition of traffic was essentially the same for each pair of sites, as both were on the same highway.

The speed data was collected in the field by using a speed radar device. When collecting speeds at sites with an LSR, the direction of highway traffic observed was that adjacent to the service road, i.e. the LSR was on the drivers' right. At the corresponding locations with direct access, the observations were taken in the same direction if in an adjacent area, or in the opposite direction if across the highway.

Questionnaire Data

A final consideration of this study was the attitude and experience of various elements of the public in regard to access control by the use of service roads. For this purpose two interview forms were devised, one directed toward owners or managers of business establishments, the other intended for their customers. It was soon discovered that to interview customers during their stay at the businessplace was impractical. This form, however, was used to interview residents, wherever feasible, who lived on service road sites.

The business form (see Appendix A) is concerned with volume of business, approximate trip generation, the amount of floor space, and the value of land along the highway frontage. The customer form (see Appendix A) deals largely with the matter of accessibility to roadside

establishments. Both forms were used to evaluate the safety aspects of service roads, and requested suggestions for improvement or redesign of the study area.

ANALYSIS OF DATA

Classification of Intersection Types

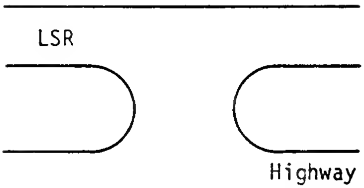
The analysis of data, especially accident and conflicts data, was organized around a classification scheme for service road intersections and access points. Figures 2 and 3 show the types of intersections studied, and the number of each for which conflicts data was collected.

The intersections studied were grouped into local service road (LSR) intersections and highway intersections. This distinction was deemed necessary because entire intersections involving both the LSR and the highway could not be readily studied as a single unit, and in addition, the amount of variability among sites would have been beyond any meaningful classification. Even as classified two intersection types could not be included in the conflicts comparison due to their low frequency of occurence. Some crossroad locations were to private commercial drives although most were to public streets.

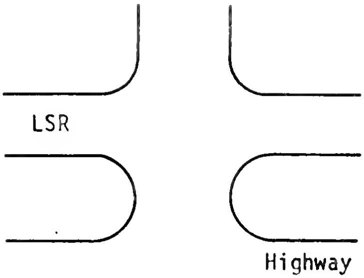
Conflicts Comparison

In reviewing the data collected from the conflicts count, it appeared that several of the conflict categories on the data sheet were insignificant, thus the conflicts and their associated volumes were narrowed down to only those involving turning and cross movements. All traffic movements into or from the wrong lane, weaving movements, and all rear-end conflicts except slow for turns were therefore eliminated from consideration.

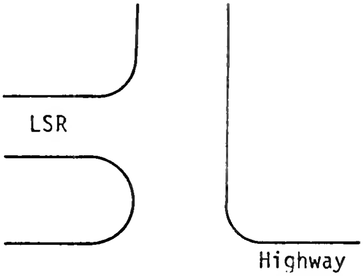
The number of conflicts in the remaining categories and their associated turning or cross volumes for each approach were summed for the ten-hour period, resulting in the number of conflicts, C, and the number of turning or cross vehicles, TV. A third number, the approach volume, AV, was computed for the same ten-hour period as the sum of the thru, right-



Type A: Three - Legged LSR Intersection, 7 sites



Type B: Four - Legged Intersection of LSR with Crossroad, 11 sites



Type D: Intersection of LSR Terminus at Crossroad, 9 sites

Figure 2. Local Service Road Intersection Types Studied

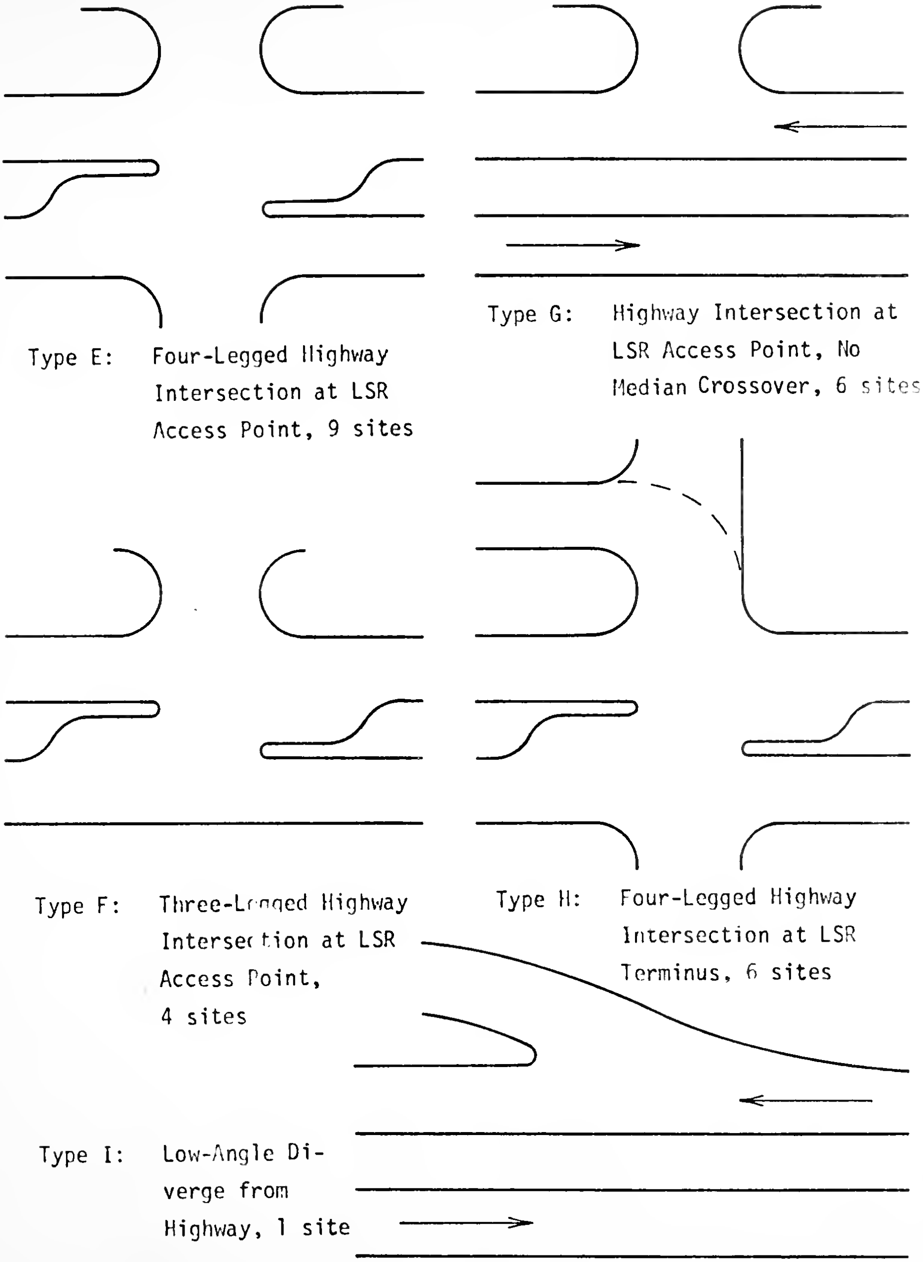


Figure 3. Highway Intersection Types Studied

turn, and left-turn vehicles on each approach. Where the configuration of the intersection precluded any particular maneuver, only those possible within the movements of interest were included.

At the three types of service road intersections, conflicts counts were made on the service road approaches. Initial analysis revealed an additional need for counts on the crossroad approaches of Types B and D. Time and distance considerations prevented a return to all such Type B and D sites, but those on which crossroad conflicts counts were made appeared sufficient to estimate conflicts at those intersections not counted. With the volume of all turning and cross movements and approach vehicles available for each crossroad approach, the numbers of crossroad conflicts were estimated from the trends in the known crossroad conflicts counts.

A search for some measure of the performance of each intersection was initiated by summing the conflicts (C), turning movements (TV) and approach volumes (AV) in the following manner for the several types of intersections:

Type A - sum on opposite approaches of the service road to the intersection.

Types B and D - sum on all approaches to the service road intersection.

Types E. G. and H - sum on opposite approaches of the highway to the intersection.

The above summations resulted in ΣC, ΣTV and ΣAV for each intersection.

These values were then combined into an index K for each intersection by use of the model $\Sigma C = K\frac{\Sigma TV}{\Sigma AV}$. The rationale behind the development of this model was that the conflicts index K would be an adjustment factor dependent on the safety performance of the intersection resulting from the number of conflicts C and the opportunity for a conflict TV/AV.

The K values for each site were calculated and classified into their appropriate type as shown in Table 2. A higher index indicates a poorer safety performance. Where the number of conflicts at an intersection was zero, an approximation of $\frac{\Sigma C}{\Sigma TV}$ of the form $\frac{1}{4(TV)}$ was made to approximate a normal distribution. This correction was suggested by Bartlett and

Table 2. Tabulation of "K" Values by Intersection Type

Type A (LSR Intersection)

Intersection No.	01	06	09	11	13W††	15
ΣC/ΣTV	1/412*	1/156*	1/112*	1/222	1/28*	1/1212*
ΣAV	71	92	57	103	6	141
K = (ΣC/ΣTV)ΣAV	0.172	0.590	0.509	0.464	0.214	0.116

Intersection No.	16
ΣC/ΣTV	6/291
ΣAV	484
K = (ΣC/ΣTV)ΣAV	9.979

Type B (LSR Intersection)

Intersection No.	02	03	04	08	10	12
ΣC/ΣTV	15/597	3†/275	5†/392	3†/511	2†/393	5/462
ΣAV	179	108	158	193	143	179
K = (ΣC/ΣTV)ΣAV	4.497	1.178	2.015	1.133	0.728	1.937

Intersection No.	18	20	21	24	27
ΣC/ΣTV	7†/1061	2†/240	1†/189	1†/288	1†/380
ΣAV	411	109	82	134	170
K = (ΣC/ΣTV)ΣAV	2.712	0.908	0.434	0.465	0.447

Type D (LSR Intersection)

Intersection No.	07	13E	14E	14W	19	22
ΣC/ΣTV	2†/193	1†/106	1/842*	2/172	17/984	1†/153
ΣAV	111	28	174	288	693	47
K = (ΣC/ΣTV)ΣAV	1.150	0.264	0.207	3.349	11.973	0.307

Intersection No.	23	25	26
ΣC/ΣTV	5/690	2/451	1†/262
ΣAV	499	410	231
K = (ΣC/ΣTV)ΣAV	3.616	1.818	0.882

††insufficient volumes to yield reliable data, rejected from analysis

*1/(4TV) approximation †crossroad conflicts estimated from known data

Table 2., cont.

Type E (Highway Intersection)

Intersection No.	02	04	10	11	12
ΣC/ΣTV	10/273	8/66	1/872*	1/260	1/1084*
ΣAV	3481	3567	5431	5359	4348
K = (ΣC/ΣTV)ΣAV	127.509	432.364	6.228	20.612	4.011

Intersection No.	16	20	21	24
ΣC/ΣTV	9/341	9/143	7/101	10/174
ΣAV	4218	2980	3070	3120
K = (ΣC/ΣTV)ΣAV	111.326	187.552	212.772	179.310

Type G (Highway Intersection)

Intersection No.	03	06	08	09	15	18
ΣC/ΣTV	1/32	1/34	1/316*	1/84*	1/612*	20/148
ΣAV	1861	1335	2728	2617	3261	2349
K = (ΣC/ΣTV)ΣAV	58.156	39.265	8.633	31.155	3.858	317.432

Type H (Highway Intersection)

Intersection No.	05	13E	14E	14W	22	23
ΣC/ΣTV	13/102	1/36	1/1132*	1/191	7/66	4/607
ΣAV	3491	3675	3788	3788	3230	2670
K = (ΣC/ΣTV)ΣAV	444.931	102.083	3.346	19.832	342.576	17.595

---

*1/(4TV) approximation

shown by Eisenhart (15) to be a good approximation where one event associated with another does not occur in a small sample.

These six groups of intersection conflict indices were considered as six samples, and a comparison of the intersection performance was made among types. A one-way analysis of variance (ANOVA) technique is useful in testing the hypothesis of equality of population means. Before this test can be run with valid results, however, two assumptions must be met.

The first of these, the normal distribution of the populations in each type, was examined by the Shapiro-Wilk W-test for normality (5). This procedure is performed in five steps, described as follows:

1. Rank the n individual sample observations in increasing order.
2. Compute the sum of the squared deviations from the sample mean, i.e., $\sum_{i=1}^{n} (\overline{Y} - Y_i)^2$, where $\overline{Y} = \sum_{i=1}^{n} Y_i/n$
3. Compute
$$b = \sum_{i=1}^{k} a_{n-i+1} (Y_{n-i+1} - Y_i)$$
where the value of a_{n-i+1} is determined from a table using the sample size n.
4. Compute
$$W = b^2 / \sum_{i=1}^{n} (\overline{Y} - Y_i)^2 .$$
5. Compare W to the percentage points given in a table by the desired level of confidence. Small values of W indicate non-normality.

For Types A and G the hypothesis of normality was rejected at the 0.05 level of significance, thus indicating a need for a transformation. The $\sqrt{y + 1}$ transformation yielded acceptable results for all types except A, for which it was decided to isolate site 16 from the analysis, as it appeared to be a case of its own. Normality was then achieved for all types, and testing on the second assumption proceeded.

The second assumption, homogeneity of the variances of all the types, was examined with the aid of the Burr-Foster Q statistic (5). For equal sample sizes, n, from each of p parent populations, let S_j^2 (j=1,....p) denote the jth sample variance. Denoting the value of the test statistic Q by q, $q = (s_1^{\,4} + . . . + s_p^{\,4}) / (s_1^{\,2} + . . . + s_p^{\,2})^2$.

For unequal sample sizes, each sample variance, s_j^2, is calculated by dividing by the degrees of freedom, v_j, rather than by the sample size, n_j (where $v_j = n_j - 1$, for $j = 1, \ldots p$). Let $\bar{v}$ denote the arithmetic average of the degrees of freedom. Then,

$$q = \bar{v}(v_1 s_1^4 + \ldots + v_p s_p^4) \;/\; (v_1 s_1^2 + \ldots + v_p s_p^2)^2.$$

Large values of Q lead to rejection of the hypothesis of equal population variances. The critical value for the test is read from a table of critical Q values, at the 0.999 level. If the computed value is less than the table value, the hypothesis is accepted, otherwise a transformation could be performed, or the types rearranged.

Testing of the equality of all the six variances indicated substantial non-homogeneity of variance among them. It appeared that the variances for service road intersections were considerably lower than those of the highway intersections, thus a division of this order was made in the intersection types. These two groups of three variances were then separately tested for homogeneity, resulting in the acceptance of the hypothesis of equality in both cases. Thus the need for separate testing of the service road and highway conflicts indices was indicated.

A Purdue University computer program by the name of BMD1V was used to perform the two one-way analyses of variance. The results are presented in Table 3. Using a test level of 0.95 for the F-test, the critical value of F for the service road intersection types is $F_{.05(2,22)} = 3.44$. Since the calculated F ratio of 1.95 is less than 3.44, the hypothesis of no significant differences in the mean conflicts index for the three service road intersection types is accepted. Similarly, the critical F value for the highway intersection types is $F_{.95(2,19)} = 3.51$. Again the calculated F ratio of 0.90 is less than 3.51 and the hypothesis of no significant differences in the mean conflicts index for the highway intersection types is accepted.

The above results indicate that the safety performance of the three LSR intersection types was essentially the same, as was that for the three highway intersection types. That is, no one design of those studied for the service road or the highway intersections was significantly safer than the others.

Table 3. Analysis of Variance Table for Conflicts Indices

Service Road Intersection Types:

Source	Sum of Squares	Degrees of Freedom	Mean Square	F - Ratio
Between Groups	1.14	2	0.57	1.95*
Within Groups	6.44	22	0.29	
Total	7.58	24		

Highway Intersection Types:

Source	Sum of Squares	Degrees of Freedom	Mean Square	F - Ratio
Between Groups	78.27	2	39.13	0.90*
Within Groups	823.50	19	43.34	
Total	901.77	21		

*Not Significant

It should be noted however, that the reliability of these findings depends upon the variations of design and volumes found at each site, as well as the number of sites found for each intersection type. With a considerable range of design and operational experience apparent for the small number of sites found, it may be that the variability within the types overshadows any variability among the types. This phenomenon may be the reason why no significant differences were detected, a finding contrary to what one might expect.

Regression Analysis for Factors Influencing Conflicts

A consideration of two studies in the bibliography gave rise to the idea of attempting to explain the occurrence of conflicts on the basis of traffic and/or geometric factors. A study by the Ohio Department of Transportation (50) sought to form an equation relating conflicts to accident experience, and research by J. A. Head of the Oregon State Highway Department attempted to predict accidents on the basis of roadway elements for sections of highways (24). Thus the question appears, "Why not try to predict conflicts on the basis of such roadway elements?"

This research study, although resulting in a limited amount of information at a relatively small number of various types of intersections, was interested in determining those factors which help to explain the occurrence of conflicts. Those factors which were found to be most important could then serve as possible indicators of service road intersection design and location.

A list of geometric and traffic factors which are suspected of playing a part in intersection performance was developed and is given in Table 4. Details of calculations are shown in Appendix C for the various types of intersections. The values for traffic items were taken from the ten-hour volume counts.

Where individual intersections within a type indicated no conflicts, the actual value of zero was used for that index, since normality was not required of the group index distributions in this analysis. Separate analyses were made for the service road conflicts and crossroad conflicts for Type B intersections, and since the data yielded zero conflicts on all Type D service road approaches, only crossroad conflicts were analyzed

Table 4. Factors Used in Regression Analysis of Conflicts[†]

WRD - width of the road on which conflicts were recorded, in feet

WDR - width of the road or driveway at right angles, in feet

HVS - volume* sample on road WRD

CVS - volume sample on road WDR

SVS - sample volume split, computed as CVS/HVS

VTI - total volume entering the intersection

WOS - width of outer separation in feet

TVNR - turning volume entering the service road (or highway) via right turns

TPNR - turning percentage entering the service road (or highway) via right turns

TVNL - turning volume entering the service road (or highway) via left turns

TPNL - turning percentage entering the service road (or highway) via left turns

TVN - total volume entering the service road (or highway)

TVXR - turning volume exiting the service road (or highway) via right turns

TPXR - turning percentage exiting the service road (or highway) via right turns

TVXL - turning volume exiting the service road (or highway) via left turns

TPXL - turning percentage exiting the service road (or highway) via left turns

TVX - total volume exiting the service road (or highway)

WMD - width of the highway median, in feet

CONF - conflicts index K, computed as $(\Sigma C/\Sigma TV)\Sigma AV$

[†]For illustration and method of calculation, see Appendix C.

*All volumes are for the ten-hour conflicts count period, 7:30-12:00 a.m. and 12:45-6:15 p.m.

for this type. Thus a total of seven regression analyses were conducted.

The computer program used for the multiple linear regression analysis was SPSS-15, "Regression". This program computes a sequence of multiple linear regression equations in a stepwise manner. The stepwise regression technique adds the variables, one at a time, to the regression equation. At each step the variable added is the one which has the highest partial correlation coefficient with the dependent variable, making allowance for those variables which are already in the equation. This process of selection of independent variables continues until either the variable list is exhausted or there are no variables that could add significance to the equation. A significance level of 5 percent was used for the overall regression equation.

The stepwise regression, in all cases, was performed in a manner such that all the applicable independent variables were eligible to enter the equation. However, there generally was a point at which the variables added to the equation did not significantly increase the correlation coefficient squared R^2. The value of R^2 ranges from zero to one, and the closer to one, the better the regression equation explains the effects of the independent variables on the dependent variable. Also, the fewer the number of variables to be used in equations yielding a relatively high R^2, the more reliable are the findings relative to other locations.

In order to determine the significance of the addition of a variable, a test to determine a significant increase in R^2 was conducted after the inclusion of each variable. This F-test is as follows:

$$F = \frac{(R_j^2 - R_k^2) / (j - k)}{(1 - R_j^2) / (n - j - 1)}$$

with $(j - k)$ and $(n - j - 1)$ degrees of freedom where

F - calculated F value

R_j^2 - correlation coefficient squared with j independent variables in the equation

R_k^2 - correlation coefficient squared with k independent variables in the equation

n - total number of observations

j - number of independent variables in the equation to be tested for a significant increase in R^2

k - number of independent variables in the equation to base the significant increase in R^2

These tests were conducted at a 5 percent level of significance.

An auxiliary program at Purdue University called DRRSQU, "R-Squares for All Possible Regressions", was used to detect combinations of variables which explain the conflicts index nearly as well, or possibly better than, those variables forming the regression equation. Such a program avoids the bias introduced by the stepwise criterion of adding those variables with the highest partial correlation coefficient into the regression procedure. Such a criterion may not yield the highest correlation coefficient squared. For instance, the Type B service road stepwise regression equation of three variables, each added on the basis of the highest partial correlation coefficient, did not explain the conflicts index as well as another set of three variables not entered in a stepwise fashion.

Together these programs resulted in seven regression equations which provide some explanation of the influence of traffic and geometric factors on the conflicts index at various types of intersections. The results are summarized in Table 5, where the variables are ranked by order of entry into the equation. The correlation coefficient squared for the equation used is shown, as are the number of observations on which the equation is based, and the degrees of freedom remaining for error. All of the equations developed were significant at the 0.05 level except that for Type G. There seems to be no real pattern among the types, but for individual types the findings in general seem reasonable, as will be discussed in the section on recommendations for design.

Speed Data

The objective of the speed analysis was to determine what differences, if any, exist between speeds on LSR access-controlled highways and highways with direct driveways. Suitable comparison locations were found for five of the LSR locations, thus five pairs of speed data were available for comparison.

Table 5. Summary of the Influence of Variables on the Conflicts Index, by Order of Entry into the Regression Equation

Variable	Intersection Type: Type A	Type B (on LSR approaches)	Type B (on X-road approaches)	Type D (on X-road approaches)	Type E	Type G	Type H
WRD			1st				
HVS	1st			1st			
SVS		1st					
VTI		3rd			3rd		
WOS			2nd				
WDR				2nd			
TVNR						1st	
TVN							2nd
TVXR				3rd			
TPXR			3rd			2nd	
TVX		2nd			1st		
WMD					2nd		1st
R^2=correlation coefficient squared	0.968	0.941	0.943	0.862	0.846	0.856	0.960
Number of observations	6	11	11	9	9	6	6
Degrees of freedom	4	7	7	5	5	3	3

The original approach to analysis was to examine speed differences of the ten-mph pace, but preliminary testing of the normality of the samples using the Kolmogorov-Smirnov "D" Test (49) indicated that all samples were drawn from normal populations, thus it was possible to use the mean of the samples for comparison, since with normality the mean of the pace was essentially equivalent to the mean of the sample.

The F-test is useful in checking the homogeneity of variances of the sample pairs. This test is conducted by comparing the calculated F-value, computed as the larger sample variance divided by the smaller sample variance, to a table value. Using a level of significance of 0.05, in all five cases the calculated F-value indicated homogeneity. This result is interesting in that one would anticipate more uniform speeds, and hence a smaller variance, on LSR sections due to an expected lower frequency of interruptions as a consequence of fewer access locations.

A test made to further examine this hypothesis was a one-way paired t-test to examine the difference of the percentage of sample vehicles in the pace. The LSR sections were tested to see if their pace percentages were significantly higher than those for non-LSR sections. The results were suprising in that only one pair of sites exhibited a higher percentage in the pace for the LSR section. It would appear from this test and the homogeneity test that the use of LSR access control on a highway has little effect on the uniformity of speeds.

The five pairs of samples were then tested for differences in their mean speeds by use of the two-tailed t-test. A table value is compared to the computed t-statistic, where

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{(n_1-1)s_1^2 + (n_2-1)s_2^2}} \sqrt{\frac{n_1 n_2 \ (n_1+n_2-2)}{n_1+n_2}}$$

n_i = number of observations in the ith sample

$\bar{x}_i$ = mean of observations in the ith sample

s_i^2 = variance of observations in the ith sample

In the t-test, a level of significance of 0.05 was used. The results of the testing of means are summarized in Table 6.

Table 6. Summary of Mean Speed Comparisons for Sites With and Without LSR

Highway Location	Site	Mean Speed (mph)	Result*
US 52 Bypass, West Lafayette (Two Lane Commercial, Speed Limit 45)	Without LSR	34.16	Significant Difference
	With LSR	38.04	
SR 431 - Madison Ave. Indianapolis (Four Lane Commercial, Speed Limit 40)	Without LSR	38.99	Significant Difference
	With LSR	37.54	
US 460 - Diamond Ave. Evansville (Four Lane Industrial, Speed Limit 40)	Without LSR	37.72	Difference Not Significant
	With LSR	38.49	
West Tenth Street, Indianapolis (Two Lane Residential, Speed Limit 40)	Without LSR	34.46	Difference Not Significant
	With LSR	35.22	
SR 431 - Madison Ave. Indianapolis (Four Lane Residential, Speed Limit 40)	Without LSR	38.84	Difference Not Significant
	With LSR	39.45	

*Using significance level of 0.05

The pattern of differences found was a mixed one at best. While both US 52 and SR 431 in a commercial area indicated significant differences in speeds, the higher speed was found at one location where there is an LSR, and at the other where there is not an LSR. It should be noted that on SR 431 both commercial area samples used outbound traffic but the site without an LSR was approaching rural undeveloped land, although the location of the speed measurements was developed similarly to that on the location with an LSR. At the other three locations the site with an LSR indicated higher speeds, although not to any significant degree.

From these results it would appear that no significant increase of speed is evident where service roads exist. That is to say, drivers are conservative in not increasing their levels of speed when they pass through LSR access-controlled locations. Thus, in regard to speeds on the highway, LSR locations should be no more dangerous than direct access locations.

Questionnaire Data

Business Survey

The discussion of replies and findings of the business survey is organized on the basis of the survey questions (see Appendix A) and land use class of the establishment. A total of fourty-eight firms were interviewed, thirty-five of these located on a service road, and thirteen having direct access to the highway on similar sections, where the questions were posed on the supposition that a service did exist at the location. Each establishment was classified into an appropriate category, these being office, retail, service, restaurant, or recreational.

Question #1 was an open-ended question concerning the safety of accessibility for business customers where an LSR is utilized. The analysis of the replies to this question indicated several common themes in the variety of answers given, with some individual establishments expressing multiple themes. Seven typical opinions were detected as given in Table 7.

Table 7. Summary of Replies Given to Question #1

1. How is the safety of your customers affected by your being located on a service road?

Typical Opinions Detected*

	i	ii	iii	iv	v	vi	vii
Office	2 (1)	4 (1)	1	(1)	2		3
Retail	3	2 (1)	2 (1)	(1)	3	1 (1)	2
Service		2 (1)	2		1 (1)	1 (2)	
Restaurant		1		1	1 (1)	1 (2)	
Recreational					1		
Sum	5 (1)	9 (3)	5 (1)	1 (2)	8 (2)	3 (5)	5

_ number of times mentioned from establishments at LSR locations

( )number of times mentioned from establishments at non-LSR locations

*Typical Opinions Detected

i. Better circulation and improved parking conditions in the travel corridor

ii. Safer for turning maneuvers due to reduced number of drives from the highway

iii. Slower or less traffic at driveway to business location adds to customer safety

iv. Improved visibility for drivers because of open area of outer separation

v. Recognized as safer with LSR for various other reasons or no particular reason

vi. No differences in safety apparent

vii. More dangerous due to LSR

The service road was mentioned as creating additional hazards only five times and making no difference eight times. Major safety improvements recognized were the reduced number of drives to highway, mentioned twelve times, and general improvement, mentioned ten times. Of the fourteen items mentioned by non-LSR firms, nine fell into the five categories of increased safety, indicating that even businesses with direct drives recognize certain safety benefits that can be realized from an LSR location.

Question #2 was intended to determine how business people feel about the effect of LSR access control on the long-term success of their business. Table 8 reveals that twice as many businessmen whether already on an LSR or not recognize the need to preserve the ability of the highway to carry traffic. Interestingly, restaurants were just as cognizant, if not more so, about the problem of travel deterioration than were the other classes.

The third question asked the businesspeople for their evaluation of the effect of an LSR location on their potential volume of business. The results of business experiences on LSR locations are often of considerable interest to other firms concerned about losing business due to an indirect type of access. LSR firms reported mostly no difference in volume of business and tended toward, if anything, a beneficial appraisal, as shown in Table 9. The fear of non-LSR establishments toward LSR locations was evident although not to a major degree, possibly because some of these firms were already experiencing firsthand some loss of volume arising from the deterioration of the ability of the highway to carry traffic.

Question #4 sought to compare the effects of two geometric elements, namely the median and the LSR, on the volume of business. These two elements and their associated access openings play a major role in the accessibility of highway traffic to roadside establishments. The results, summarized in Table 10, indicated that businesspeople feel these two exert a nearly equal influence on the number of customers. Two respondents felt that the elements could not be separated, but rather together they coordinate to determine business accessibility.

Table 8. Summary of Replies Given to Question #2

2. Comment on the hypothesis that the preservation of the traffic-carrying capability of the arterial street is essential to the continued success of your business.

	Reply Given				
	Total	Agree	Disagree	Does Not Matter	No Answer
Office	11 (2)	4 (1)	2	2	3 (1)
Retail	11 (2)	4 (3)	2 (1)	1	4
Service	8 (4)	3 (1)	2 (1)	1 (1)	2 (1)
Restaurant	4 (3)	3 (1*)	0 (1)	0	1 (1)
Recreational	1	0	0	1	1
Sum	35 (13)	14(6)	6 (3)	4 (1)	10 (3)

( )number of establishments at LSR locations
__number of establishments at non-LSR locations
* Agrees where business is well-known name

Table 9. Summary of Replies Given to Question #3

3. What do you feel is the effect of being located on a service road on your potential volume of business?

	Reply Given				
	Total	Beneficial	Detrimental	No Difference	No Answer
Office	11 (2)	1 (1)	2	7 (1)	1
Retail	11 (4)	3 (2)	2 (1)	6 (1)	0
Service	8 (4)	2	0 (2)	6 (1)	0 (1)
Restaurant	4 (3)	1	0 (2)	3 (1)	0
Recreational	1	0	0	1	0
Sum	35 (13)	7 (3)	4 (5)	23 (4)	1 (1)

( )number of establishments at LSR locations
__ number of establishments at non-LSR locations

Table 10. Summary of Replies Given to Question #4

4. Do you feel that the service road or the median has the greater effect on the number of your customers?

	Total	LSR	Median	Must Coordinate	No Difference	No Answer
Office	11 (2)	3 (1)	4	1	3 (1)	0
Retail	11 (4)	2	3 (3)	1	4	1 (1)
Service	8 (4)	2 (1)	1 (1)	0	5 (1)	0 (1
Restaurant	4 (3)	1	0	0	1	2 (3)
Recreational	1				1	
Sum	35(13)	8 (2)	8 (4)	2	14 (2)	3 (5)

( )number of establishments at LSR locations
__ number of establishments at non-LSR locations

Table 11. Summary of Replies to Question #8

8. How do you feel the service road has affected the value of land along it?

	Total	Higher	Lower	No Difference	No Answer
Office	11 (2)	3	2	5 (2)	1
Retail	11 (4)	8*(2)	1	2 (2)	0
Service	8 (4)	4	0	4 (3)	0 (1)
Restaurant	4 (3)	2	0	1 (2)	1 (1)
Recreational	1			1	

( )number of establishments at LSR locations
__ number of establishments at non-LSR locations
* ability to move among stores via LSR cited often

The final item subjected to analysis was the businesspeoples' evaluation of the effect of an LSR on the value of roadside land as an indication of its commercial worth. An examination of Table 11 reveals three major findings, First, none of the merchants with direct access to the highway felt that an LSR decreases the value of roadside land, and only three businesspeople on an LSR felt that it does. Second, in comparing the replies of LSR business to non-LSR businesses, it appears that once a businessperson has experienced the operation of an establishment at an LSR location, he finds it to be worth more. The third finding is that retail merchants both at LSR and non-LSR locations felt considerably more often than the other land uses that roadside property where there is a service road would have greater value. A reason often cited was the realization that customers had a greater ability to move among stores where a service road existed.

Residential Survey

Twelve residents in all were interviewed on two locations (Homecroft and Clarksville).

Question #1 was concerned with the frequency with which someone in the household drove a car on the service road. The typical response of 5 or 6 times per day indicates that the service road receives a fair amount of use.

Question #2 asked about the effect of the LSR on the safety of accessibility to the residences, with three typical themes noted in the responses as follows:

- 6 responses - safer to back out of driveway with slower, less traffic
- 3 responses - safer entrance to and exit from the highway with spaced access points
- 2 responses - ability to reach some locations without having to use the highway adds to safety

One additional response indicated an increased feeling for the safety of children. All the residents interviewed considered the service road as a safety benefit.

Question #3 sought to determine the amount of flexibility in movement derived from the service road, this being most apparent when the

highway is congested. Three respondents indicated no difference in their ability to move around, but the other nine mentioned ability to use the local streets or entering the highway at LSR terminal points as an aid to movement.

Whatever inconvenience of accessibility that might exist at LSR locations is insignificant, according to nine respondents to question #4. One person did indicate inconvenience, but in addition mentioned that he didn't mind making the extra turns. Two residents did not respond to this question.

Question #5 was about the median versus service road inconvenience and was the same as #4 on the business form. Here the results were more distinguishable, with six residents calling the median more inconvenient to one for the service road. Two respondents felt there was no difference, and three were not able to answer. This result when coupled with that of question #4 indicates that clearly the residents consider their service road as little, if any, inconvenience.

The response to question #7 was overwhelmingly (10 of 12) in favor of more service roads along Indiana highways, at least in residential areas. Some respondents also mentioned more use of them in commercial areas as well. The one individual who did not endorse the service road concept nevertheless realized the value of access control by preferring back-in development.

Among the changes in design suggested by question #6 were a need to alleviate delay from backed-up crossroad traffic at the LSR terminus in Homecroft, and an extension to a nearby supermarket, also in Homecroft. At Clarksville mention was made of wrong-way movements at a service road entrance having a divider.

Summary

The questionnaire aspect of this study, intended to clarify the attitudes of businesspersons and residents toward service road access control, has revealed a general public recognition of increased safety at service road locations. The businesses in this survey were largely aware of the possibility of excessive access being their undoing due to its effect on the traffic-carrying capability of the highway. The most

gratifying finding was that businesses located on service roads experienced at least no loss of volume due to a service road location, with more businesses reporting gains than losses.

Accident Data

Three-Legged LSR Intersection - Type A (see Figure 2)

A total of seven three-legged LSR intersections at highway access locations, such as shown in Figure 4, were investigated for their accident patterns. Most of these were at low volume residential or commercial locations where no accidents were found to occur.

Altogether, for all service road intersections of this type studied, only two accidents were found to occur, both at site 16 (see Figure 5) which was by far the most heavily traveled. A collision diagram of this intersection is shown in Figure 6. One of the accidents involved a motorcycle passing on the left as an LSR vehicle turned left into the opening, while the other collision was a head-on meeting of an opposing left turn vehicle in front of a city bus. There appears to be no contribution of the site to these incidents unless it would be the reverse curve flare which might make oncoming vehicles less visible to left-turning vehicles. It should be noted that these accidents represent the experience of only the last year and one-half of the four and one-half year study period. Earlier accident records for this intersection were not available. There were two other access-openings of this type with similar turning volumes to the one with accidents but their approach volumes were considerably lower.

Four-Legged Intersection of LSR with Crossroad - Type B (see Figure 2)

Out of the eleven intersections grouped in Type B (see Figure 7) six had no recorded accidents. Two other intersections of the Type B configuration which were not used in the conflict analysis also had an accident history. Thus a total of thirteen four-legged LSR sites were considered for their accident patterns, five at uncontrolled intersections, eight

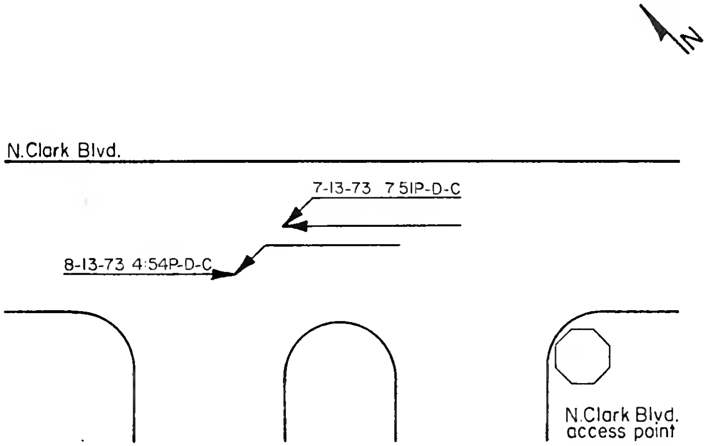
Figure 4. A Typical Three-Legged LSR Intersection at a Highway Access Point

Figure 5. The Reverse Curve of this Three-Legged LSR Intersection May Have Contributed to Two Accidents

COLLISION DIAGRAM and TABULAR SUMMARY

City Clarksville Period: from Jan. 1, 1973 to June 30, 1974

Location 630 N. Clark Blvd. @ opening to US 460



TYPE	TOTAL PI	TOTAL PD	TOTAL FA	TOTAL ALL
Right Angle				
Rear End				
Head On		1		1
Side Swipe: Opp. Dir.				
Same Dir.	1			1
Wrong Lane: Lt. Turn				
Rt. Turn				
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control				
Pedestrian				
U-Turn				
Other				
TOTAL	1	1		2

Date Compiled August 1974

Traffic Controls STOP sign

Data Source Clarksville PD

Analyst A. Baughman

Figure 6. Collision Diagram for Site 16

Figure 7. A Typical Four-Legged Intersection of an LSR with a Crossroad

with controls.

Uncontrolled Intersections. Site 02 (see Figure 8), adjacent to a four-legged highway intersection with median crossover, and site 03, opening into only one direction of highway traffic where there is no median break, both experienced right angle collisions of similar nature. At each site one accident involved a vehicle crossing the service road from the commercial establishment colliding with a vehicle coming from the right on the service road. An additional accident at the more heavily used site 02 (see Figure 9) involved a vehicle crossing the service road upon exiting from the highway and colliding with a vehicle coming from the right on the service road. At neither of these sites was any traffic control in effect, and at both, the separation between the LSR and the highway was only twenty feet. It would appear that this service road represents an unrecognized intersection to some of the vehicles crossing it. It should be noted that a third four-legged intersection on this service road (site 04, see Figure 10) with STOP control on the service road but a considerably lower number of crossing vehicles experienced no recorded accidents.

Site 27 is another uncontrolled four-legged LSR intersection where some brick planters were erected on all four corners (see Figure 11), the crossroad being the main entrance to a subdivision. These planters were cited as a visibility-limiting factor in a right-angle collision of a service road vehicle and a vehicle coming from the right on the crossroad.

Another uncontrolled four-legged intersection was site 08, where one corner of the intersection extends into a parking lot (see Figure 12). Although the crossroad opens into only one direction of traffic on the highway, this site experienced two right-angle collisions, one with personal injury (see Figure 13), involving a vehicle crossing the service road from behind the parked cars on the right. This situation illustrates the need for driveway and parking design and control on the service road as well as on the highway.

This same service road has another uncontrolled four-legged intersection farther down the road where the amount of cross-traffic at the LSR is very small even though the highway provides a median crossover; this site experienced no recorded accidents.

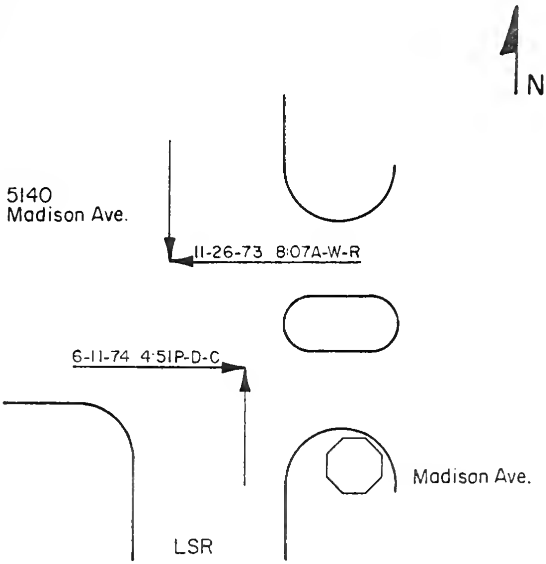
Figure 8. A Four-Legged LSR Intersection Where Two Right-Angle Accidents Occurred

Figure 10. This Four-Legged LSR Intersection With STOP Control Experienced No Accidents

COLLISION DIAGRAM and TABULAR SUMMARY

City Indianapolis Period: from Jan. 1, 1970 to June 30, 1974

Location Madison Court Driveway and LSR (@ 5140 S. Madison Ave. - SR 431)



TYPE		TOTAL		
	PI	PD	FA	ALL
Right Angle		2		2
Rear End				
Head On				
Side Swipe: Opp. Dir.				
Same Dir.				
Wrong Lane: Lt. Turn				
Rt. Turn				
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control				
Pedestrian				
U-Turn				
Other				
TOTAL		2		2

Date Compiled July 1974

Traffic Controls None

Data Source Marion Co. Sheriff

Analyst C. Baughman

Figure 9. Collision Diagram for Site 02

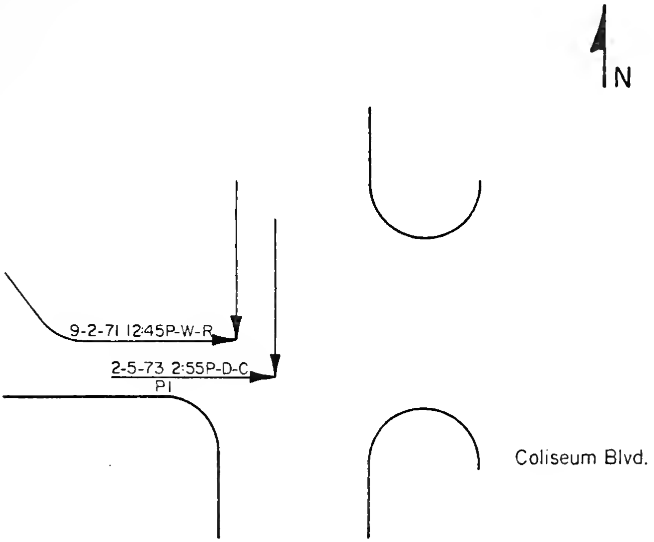
Figure 11. The Brick Planters at this Location Limit Driver Visibility at the Intersection

Figure 12. The Vehicles in the Parking Lot Conceal the Presence of Crossroad Traffic Coming from the Right

COLLISION DIAGRAM and TABULAR SUMMARY

City Fort Wayne Period: from Jan. 1, 1970 to June 30, 1974

Location Stoller Bldg. Driveway and LSR (@ 909 N. Coliseum Blvd. - US 30)



TYPE	TOTAL PI	PD	FA	ALL
Right Angle	1	1		2
Rear End				
Head On				
Side Swipe: Opp. Dir.				
Same Dir.				
Wrong Lane: Lt. Turn				
Rt. Turn				
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control				
Pedestrian				
U-Turn				
Other				
TOTAL	1	1		2

Date Compiled August 1974

Traffic Controls None

Data Source Ft. Wayne Traf. Dept.

Analyst C. Baughman

Figure 13. Collision Diagram for Site 08

Controlled Intersections. In general, the eight controlled intersections, one of which has already been discussed, experienced a safer accident history than the uncontrolled locations. The types of control in effect were STOP and YIELD, and were applied to the service road approaches. At three similar sites in the Homecroft residential area of Indianapolis (see Figure 14), all controlled by STOP signs, only one accident occurred, this a right-angle collision between a vehicle disregarding a STOP sign (at 1 a.m. in the morning) and a vehicle moving into the highway intersection from the right. Although there may be a tendency to ignore STOP signs at such low volume locations, their use is suggested for service road approaches due to the unusual traffic movements which may occur.

At two locations YIELD signs were used to control the service road traffic. The ones on a low-volume residential LSR (see Figure 7) experienced no accident difficulty, but the other more heavily used intersection (see Figure 15) in which all crossroad traffic had to turn right into the highway had two right-angle collisions, one involving personal injury, in which a service road vehicle moving through the crossroad was hit by a vehicle coming from the left toward the highway opening. It might be worth noting that a tree is present near the corner at which the two vehicles collided. Also, the traffic count at this location revealed somewhat higher volumes on the service road than on the crossroad, thus posing the dilemma of which street should be controlled. It is felt, however, that the optimum control application would be a more positive STOP control on the service road approaches, because movement of turning vehicles from the highway presents difficult problems of control.

A very unusual four-legged intersection, which was not included in the conflicts analysis, is located adjacent to a four-way signalized intersection (see Figure 16). The RIGHT TURN ONLY sign was only partially effective as indicated by the manual count and an accident (see Figure 17) which involved a left-turning vehicle being hit by a crossroad vehicle from the right. Another accident at this corner involved a vehicle turning left from the crossroad into this entrance, only to come up against an opposing vehicle which had just turned right from the highway. Also, while the STOP HERE ON RED LIGHT sign (see Figure 18) may seem like

Figure 14. A Four-Legged LSR Intersection with STOP Control on the Service Road

Figure 15. Two Right-Angle Collisions Occurred at this Four-Legged Intersection with YIELD Signs on the LSR

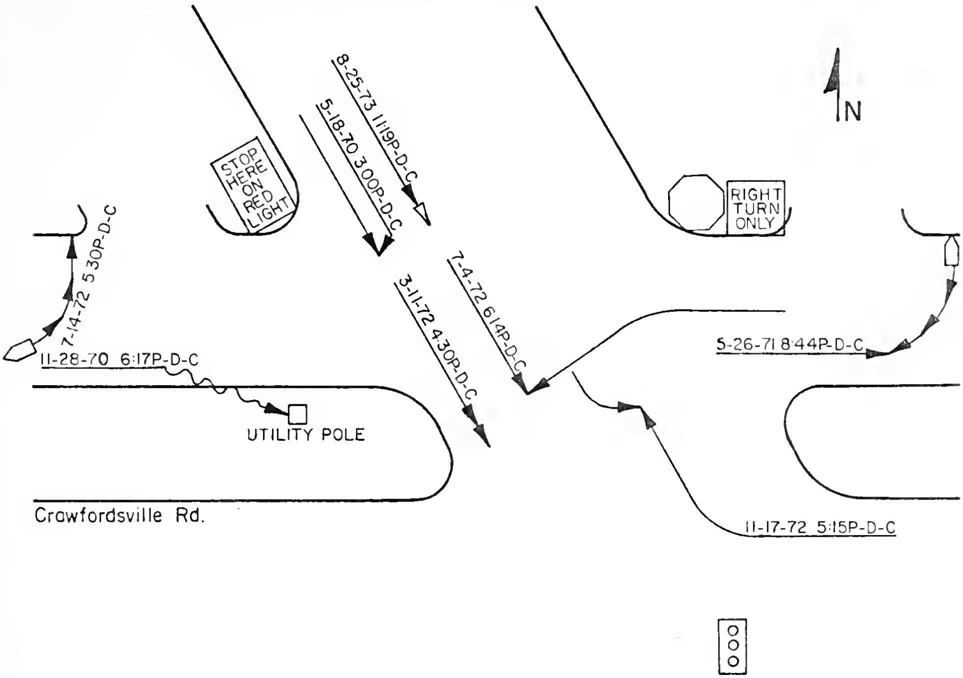
Figure 16. A Four-Legged LSR Intersection Adjacent to a Traffic Signal

Figure 18. A Service Road Passing Through a Crossroad Near a Signal Poses an Unrecognized Intersection

COLLISION DIAGRAM and TABULAR SUMMARY

City Speedway Period: from Jan. 1, 1970 to June 30, 1974

Location Lyndhurst Drive and LSR (@ 5250 W. Crawfordsville Road - US 136)



TYPE	TOTAL PI	PD	FA	ALL
Right Angle	1	1		2
Rear End		2		2
Head On				
Side Swipe: Opp. Dir.				
Same Dir.				
Wrong Lane: Lt. Turn				
Rt. Turn		1		1
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control	1			1
Pedestrian				
U-Turn				
Other (backing)		2		2
TOTAL	2	6		8

Date Compiled October 1974

Traffic Controls STOP sign, with RIGHT TURN ONLY

Data Source Speedway PD

Analyst C. Baughman

Figure 17. Collision Diagram for an Unusual Four-Legged LSR Intersection

a good idea, it may have caused some sudden or unexpected stops which could have contributed to two accidents on its approach. Again, the need for service road parking design and control is illustrated by two back-up accidents at this location.

The final four-legged LSR intersection, again excluded from conflicts analysis, which is essentially a service road terminus adjacent to a traffic signal, experienced two right angle accidents. One of these, (see Figure 19) involving a vehicle entering the LSR colliding with an opposing stopped vehicle, would indicate insufficient allowance for turning, as the separator width is only twenty feet, i.e., the radius is ten feet. The other right angle collision, to a vehicle exiting the LSR, involved a crossroad vehicle from the left which might have turned off the highway onto the crossroad, possibly appearing by surprise.

Intersection of LSR Terminus at Crossroad - Type D (see Figure 2)

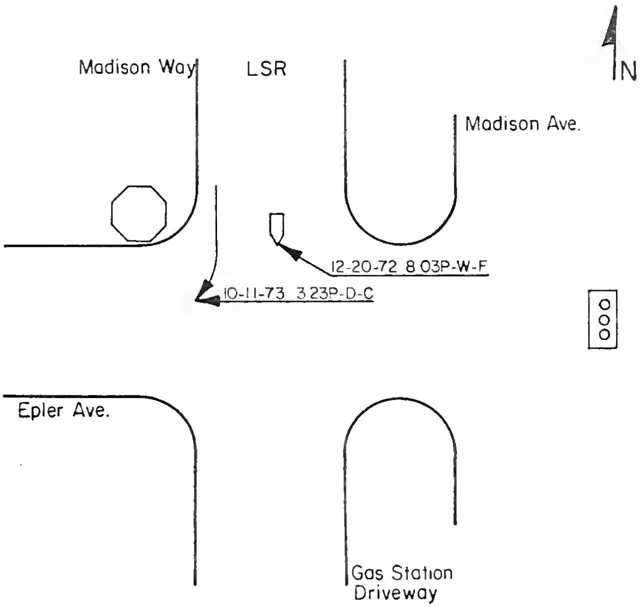
Accident experience was accumulated at nine intersections where a local service road terminated at a crossroad (see Figure 20). The width of outer separation at the crossroad ranged from five feet to ninety-five feet, also the volume of crossroad traffic counted varied from 22 to 568 vehicles in the ten hour study period. STOP sign control was used on five of the service road approaches while the rest were uncontrolled.

At only two of these locations were accidents found to occur. These two were the most heavily used in terms of LSR approach volumes and number of turning vehicles, and were both controlled by STOP signs on the service road approach. Site 19 (see Figure 21) experienced a right-angle collision involving a thru crossroad vehicle and a vehicle turning right from the service road, and also a rear-end collision involving a vehicle preparing to turn left into the service road with the rear vehicle coming from the highway intersection (see Figure 22). It is interesting to note that the conflicts count on the crossroad at this site revealed the same pattern of hazard as did the accidents, and in the case of left-turning vehicles from the crossroad, conflicts were equally prevalent to following and oncoming vehicles. These facts would suggest a widening of the outer separation to a design such as shown in Figure 23 where no such accidents and very few conflicts occurred at somewhat lower volumes. The only accident at this site and an apparently

COLLISION DIAGRAM and TABULAR SUMMARY

City Indianapolis Period: from Jan. 1, 1970 to June 30, 1974

Location Epler Ave. and LSR (@ 5500 S. Madison Ave. - SR 431)



TYPE	TOTAL PI	TOTAL PD	TOTAL FA	TOTAL ALL
Right Angle		2		2
Rear End				
Head On				
Side Swipe: Opp. Dir.				
Same Dir.				
Wrong Lane: Lt. Turn				
Rt. Turn				
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control				
Pedestrian				
U-Turn				
Other				
TOTAL		2		2

Date Compiled October 1974

Traffic Controls STOP sign

Data Source Marion Co. Sheriff

Analyst C. Baughman

Figure 19. Collision Diagram for an LSR Intersection Near a Traffic Signal

Figure 20. A Typical Intersection of an LSR Terminus at a Crossroad

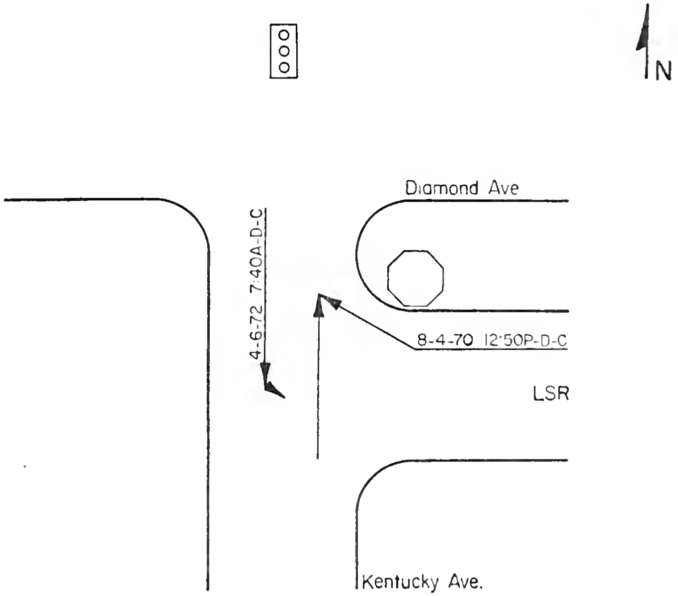
Figure 21. This LSR Terminal Intersection, Adjacent to a Traffic Signal, Experienced Two Accidents

Figure 23. This LSR Is Curved to Achieve a Greater Width of Separation at Its Terminal Intersection with the Crossroad

COLLISION DIAGRAM and TABULAR SUMMARY

City Evansville Period: from Jan. 1, 1970 to June 30, 1974

Location LSR and Kentucky Ave., near Diamond Ave. (US 460)



TYPE	TOTAL			
	PI	PD	FA	ALL
Right Angle		1		1
Rear End		1		1
Head On				
Side Swipe: Opp. Dir.				
Same Dir.				
Wrong Lane: Lt. Turn				
Rt. Turn				
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control				
Pedestrian				
U-Turn				
Other				
TOTAL		2		2

Date Compiled September 1974

Traffic Controls STOP sign on LSR

Data Source Evansville PD

Analyst C. Baughman

Figure 22. Collision Diagram for Site 19

random one involved a left-turning vehicle from the service road colliding at a right angle with a crossroad vehicle from the right (see Figure 24). Perhaps the hazard involved in this maneuver arises from the extension of the crossroad into a parking lot about thirty feet beyond the LSR where a right-angle accident occurred. All the other crossroad terminal sites experienced no difficulties in terms of accidents or conflicts, probably due largely to their low volumes.

Four-Legged Highway Intersection at Local Service Road Access Point - Type E (see Figure 3)

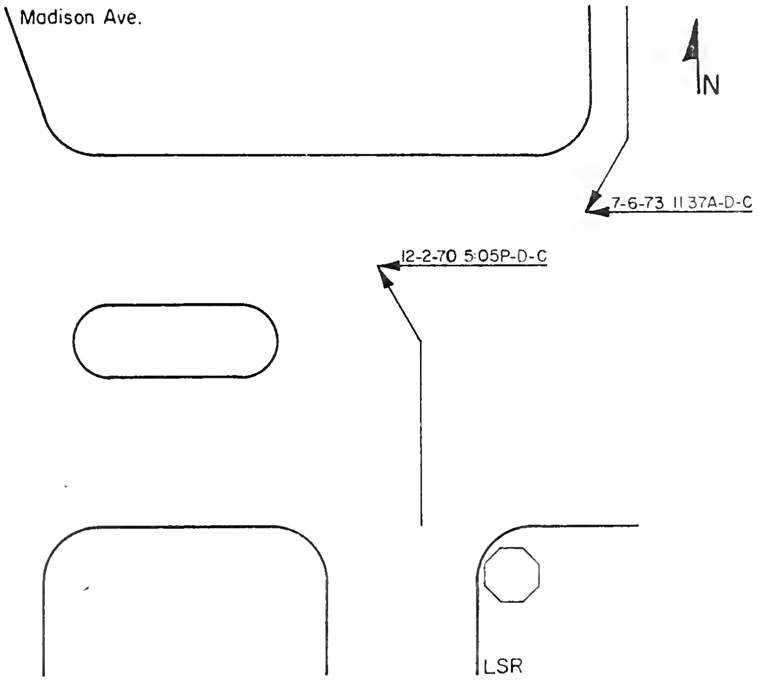
In discussing the accident patterns at eleven sites where a service road opening forms one leg of a four-legged highway intersection (see Figure 25), mention will be made of the predominant patterns and those accidents which might have been prevented by good engineering. All of the eleven gave the right-of-way to the highway traffic with the access point traffic being controlled by STOP signs or with no control devices. At one of the STOP-controlled sites, two of the accidents (see Figure 26) were right-angle collisions in which the access drive vehicle, in one case entering and one case leaving the LSR access opening, had successfully crossed the near-side highway traffic. In these cases the protection afforded by the median crossover,at fourteen feet considered inadequate here, appears to be a factor, which will receive additional discussion in a later section. The other pattern of accidents at this site was two rear-end collisions involving vehicles turning right from the highway, one of which lost control and side-swiped a vehicle waiting to enter the highway. The simple remedy at this location would be a right turn deceleration lane.

A most revealing intersection is shown in Figure 27 where a fire station on the service road is provided with access and a median opening. Left turns into the access point, where there is no protected left-turn lane, are made only 200 feet beyond a traffic signal. As one would expect, several rear-end accidents, many multi-car and known to involve left-turning vehicles, occurred at this location (see Figure 28). This hazard is created by opening the median too near a signal where no opportunity is available to provide a left-turn storage lane.

COLLISION DIAGRAM and TABULAR SUMMARY

City Indianapolis Period: from Jan. 1, 1970 to June 30, 1974

Location Creston Village Square Driveway and LSR (@ 8100 S. SR 431)



TYPE	TOTAL PI	TOTAL PD	TOTAL FA	TOTAL ALL
Right Angle		2		2
Rear End				
Head On				
Side Swipe: Opp. Dir.				
Same Dir.				
Wrong Lane: Lt. Turn				
Rt. Turn				
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control				
Pedestrian				
U-Turn				
Other				
TOTAL		2		2

Date Compiled October 1974

Traffic Controls STOP sign

Data Source Marion Co. Sheriff

Analyst C. Baughman

Figure 24. Collision Diagram for Site 23

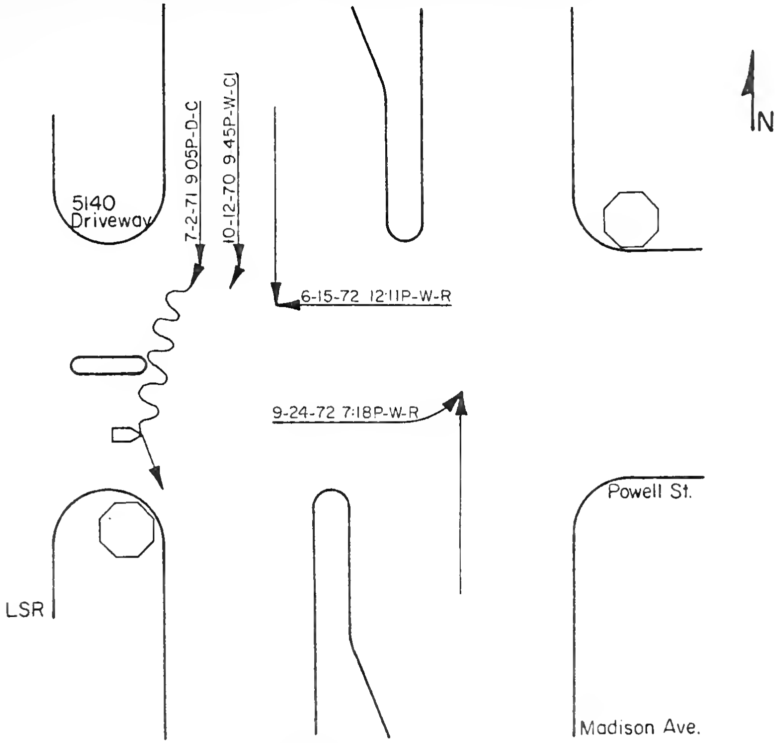
Figure 25. A Typical Four-Legged Highway Intersection at an LSR Access Point, with the Leg Opposite the LSR Access to the Left of the Picture

Figure 27. This Four-Legged Highway Intersection Has No Protected Left-Turn Lane for the Oncoming Traffic

COLLISION DIAGRAM and TABULAR SUMMARY

City Indianapolis Period: from Jan. 1, 1970 to June 30, 1974

Location 5140 S. Madison Ave. (SR 431) @ Madison Court



TYPE	TOTAL PI	PD	FA	ALL
Right Angle		2		2
Rear End	1	1		2
Head On				
Side Swipe: Opp. Dir.				
Same Dir.				
Wrong Lane: Lt. Turn				
Rt. Turn				
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control				
Pedestrian				
U-Turn				
Other				
TOTAL	1	3		4

Date Compiled October 1974

Traffic Controls STOP signs

Data Source Marion Co. Sheriff

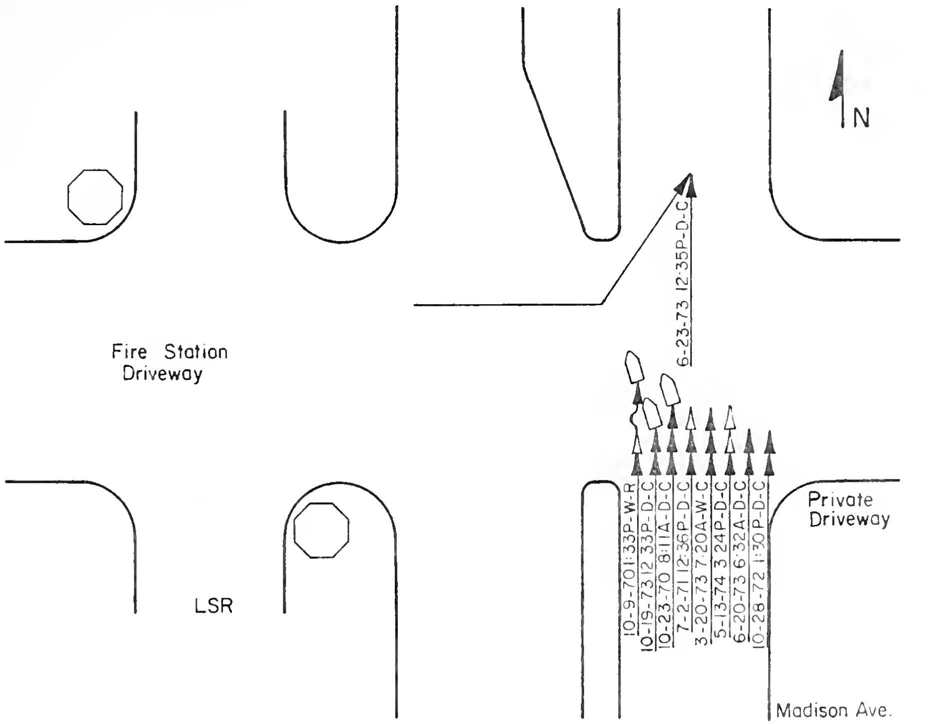
Analyst C. Baughman

Figure 26. Collision Diagram for Site 02

COLLISION DIAGRAM and TABULAR SUMMARY

City Indianapolis Period: from Jan. 1, 1970 to June 30, 1974

Location 5410 S. Madison Ave. (SR 431) @ Perry Twp. Fire Station Driveway



TYPE	TOTAL PI	PD	FA	ALL
Right Angle		1		1
Rear End	1	7		8
Head On				
Side Swipe: Opp. Dir.				
Same Dir.				
Wrong Lane: Lt. Turn				
Rt. Turn				
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control				
Pedestrian				
U-Turn				
Other				
TOTAL	1	8		9

Date Compiled October 1974

Traffic Controls STOP signs on LSR

Data Source Marion Co. Sheriff

Analyst C. Baughman

Figure 28. Collision Diagram for Site 04

The predominent pattern of accidents at site 10 was the right angle collision of vehicles crossing or making a left turn onto the highway, three with the first direction of traffic and two with the second (see Figure 29). Perhaps what is needed here is a more level grade and a clear outer separation (see Figure 30).

The site shown as typical (see Figure 25) certainly experienced its share of accidents, with several predominating patterns (see Figure 31). Again, vehicles entering the highway experienced the major problem, four with the first direction of traffic, eight with the second, and two with vehicles exiting from the opposite approach. The highway approaches to this intersection have sufficient distance and median width for left-turn lanes in both directions. Perhaps with the median width reduced by the left-turn lanes there is a hesitancy on the part of drivers to use the median as a stopping point for entering the highway. It also appears that a nearby, recent signal installation (320 feet) has helped improve the safety of this intersection, giving motorists on the service road an alternative means for entering onto the highway. Prior to the nearby signal, the average annual accident rate at the LSR opening was three per year, as compared to two per year after installation, based on the first half-year's experience. An improvement was also noted at the signalized location.

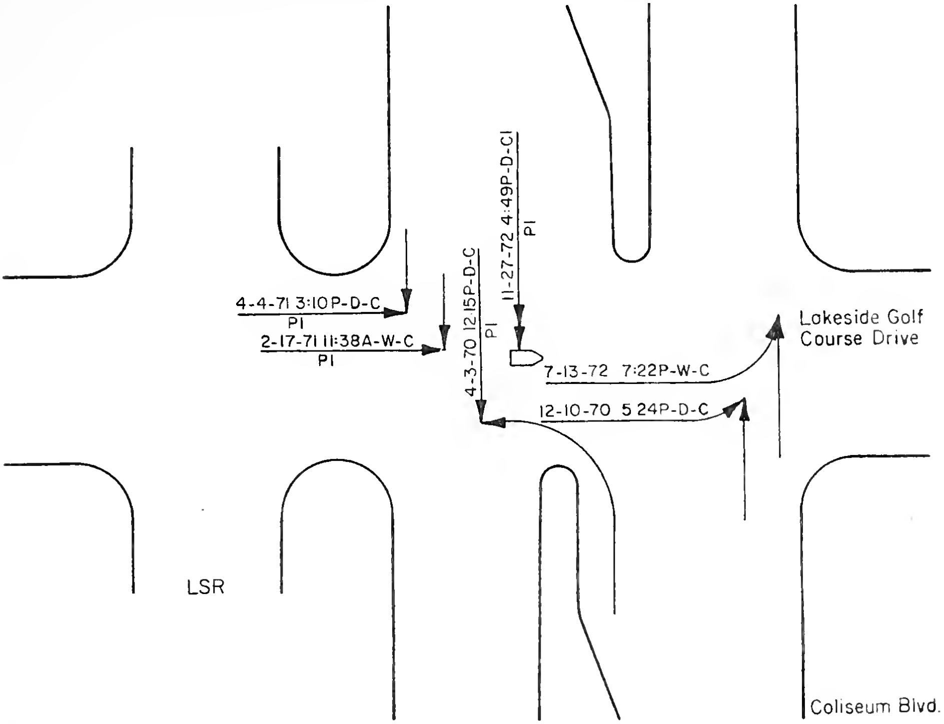
At site 12, where the crossroad on the LSR side is a major entrance into a residential area and on the opposite side a major entrance into a shopping mall, the worst accident pattern by far was right-angle collisions of vehicles crossing the highway from the shopping center to the residential street (see Figure 32). This difficulty arises from the presence of a well-used left-turn lane for the far side highway traffic. Left turning vehicles block the view of crossroad vehicles to thru highway traffic. Vehicles making a left-turn from the highway into this residential entrance also experienced to a lesser degree the same difficulty. Congestion at this intersection had developed to such an extent that it was signalized in the second half of 1974.

At the site shown in Figure 33, where accident records were available for only the last year-and-a half of the four-and-one-half year accident study period, the predominant pattern of accidents (see Figure 34)

COLLISION DIAGRAM and TABULAR SUMMARY

City Fort Wayne Period: from Jan. 1, 1970 to June 30, 1974

Location 750 N. Coliseum Blvd. (US 30 Bypass) @ crossover to Lakeside G.C.



TYPE	TOTAL			
	PI	PD	FA	ALL
Right Angle	3	2		5
Rear End	1			1
Head On				
Side Swipe: Opp. Dir.				
Same Dir.				
Wrong Lane: Lt. Turn				
Rt. Turn				
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control				
Pedestrian				
U-Turn				
Other				
TOTAL	4	2		6

Date Compiled August 1974

Traffic Controls None

Data Source Ft. Wayne Traf. Dept.

Analyst C. Baughman

Figure 29. Collision Diagram for Site 10

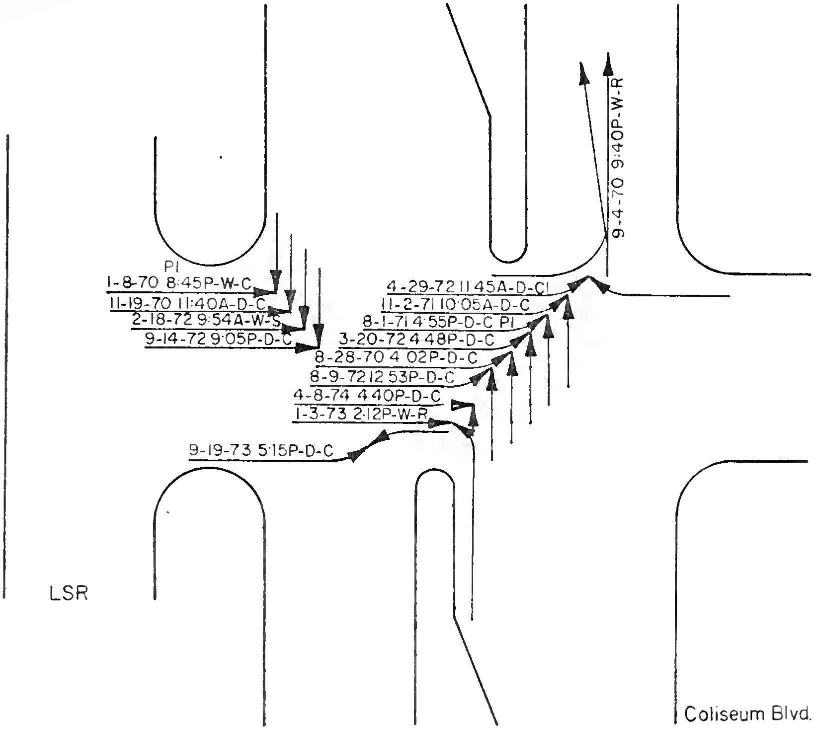
Figure 30. The Tree and Steep Grade of this Access Approach to the Highway May Have Contributed to Some Accidents at this Intersection

Figure 33. Vehicles Stopping for the Service Road Adjacent to this Four-Legged Highway Intersection May Cause Difficulties to Vehicles Entering the Access Point

COLLISION DIAGRAM and TABULAR SUMMARY

City Fort Wayne Period: from Jan. 1, 1970 to June 30, 1974

Location 1000 N. Coliseum Blvd. (US 30 Bypass) @ Crossover



TYPE	TOTAL PI	PD	FA	ALL
Right Angle	2	9		11
Rear End				
Head On		2		2
Side Swipe: Opp. Dir.				
Same Dir.		1		1
Wrong Lane: Lt. Turn				
Rt. Turn				
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control				
Pedestrian				
U-Turn				
Other				
TOTAL	2	12		14

Date Compiled August 1974

Traffic Controls None

Data Source Ft. Wayne Traf. Dept.

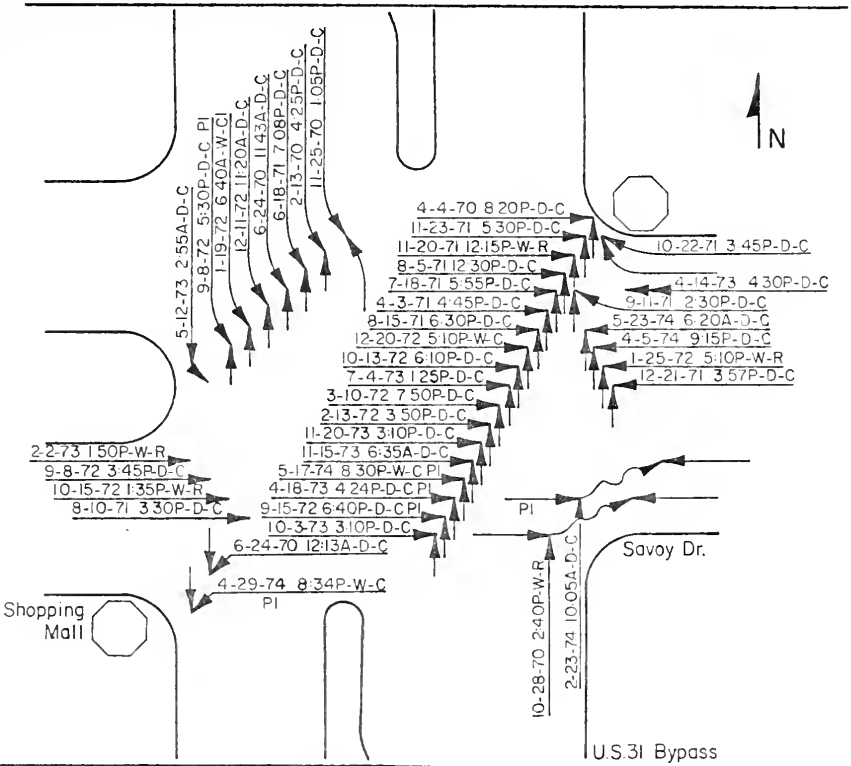
Analyst C. Baughman

Figure 31. Collision Diagram for Site 11

COLLISION DIAGRAM and TABULAR SUMMARY

City Kokomo Period: from Jan. 1, 1970 to June 30, 1974

Location 1220 S. US 31 Bypass @ Savoy Drive



TYPE	TOTAL			
	PI	PD	FA	ALL
Right Angle	6	31		37
Rear End		2		2
Head On		1		1
Side Swipe: Opp. Dir.				
Same Dir.				
Wrong Lane: Lt. Turn				
Rt. Turn		1		1
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control				
Pedestrian				
U-Turn				
Other				
TOTAL	6	35		41

Date Compiled April 1975

Traffic Controls STOP signs

Data Source Kokomo PD

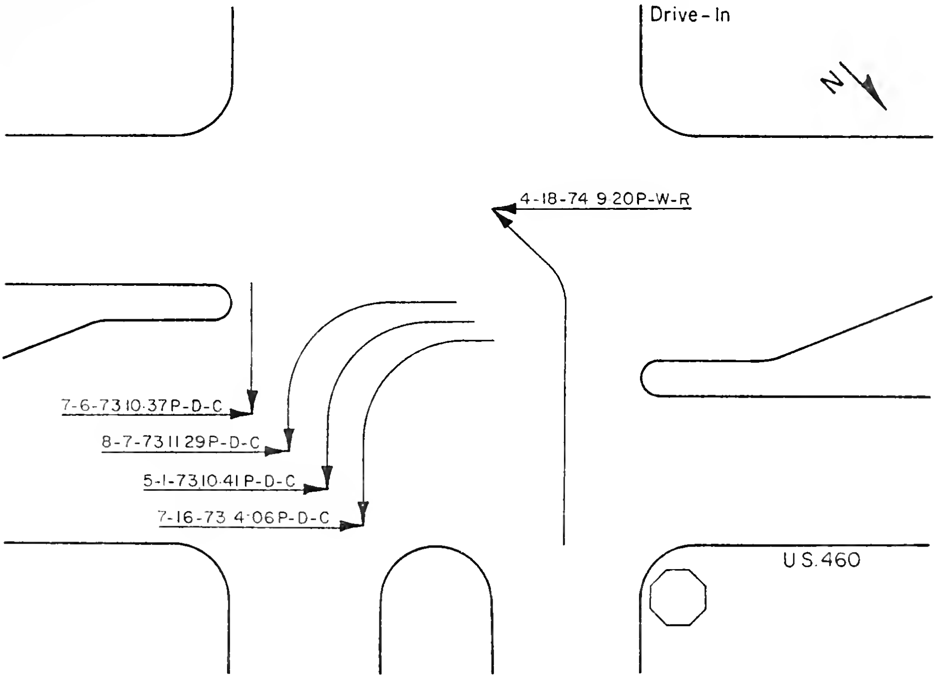
Analyst C. Baughman

Figure 32. Collision Diagram for Site 12

COLLISION DIAGRAM and TABULAR SUMMARY

City Clarksville Period: from Jan. 1, 1973 to June 30, 1974

Location 630 N. US 460 @ Clark Blvd. opening across from Drive-In



TYPE	TOTAL PI	TOTAL PD	TOTAL FA	TOTAL ALL
Right Angle	2	3		5
Rear End				
Head On				
Side Swipe: Opp. Dir.				
Same Dir.				
Wrong Lane: Lt. Turn				
Rt. Turn				
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control				
Pedestrian				
U-Turn				
Other				
TOTAL	2	3		5

Date Compiled August 1974

Traffic Controls STOP sign

Data Source Clarksville PD

Analyst C. Baughman

Figure 34. Collision Diagram for Site 16

was the three right-angle collisions of left-turning vehicles with opposing traffic as they leave the highway at the LSR access opening. This left-turning traffic is protected by a storage lane, so the only possible contributing factors would be slightly limited visibility of oncoming vehicles as they come around a curve into the intersection, or more likely the backup of vehicles into the intersection as they stop for the nearby service road. Such stopping of vehicles for the service road as required at this site is not a desirable practice.

The final four-legged highway intersection where a predominant pattern of accidents exists had no traffic control devices. On this two-lane highway the main problem was found to be rear-end accidents (see Figure 35) involving left-turning highway vehicles as they waited for a gap in opposing traffic. The State's current plans to dual-lane this highway with left-turn lanes in the median should solve this problem.

At the other four-legged highway intersections of LSR openings no noteworthy patterns were found. These locations had relatively low crossroad traffic where only isolated accidents occurred.

Three-Legged Highway Intersection at Local Service Road Access Point - Type F (see Figure 3)

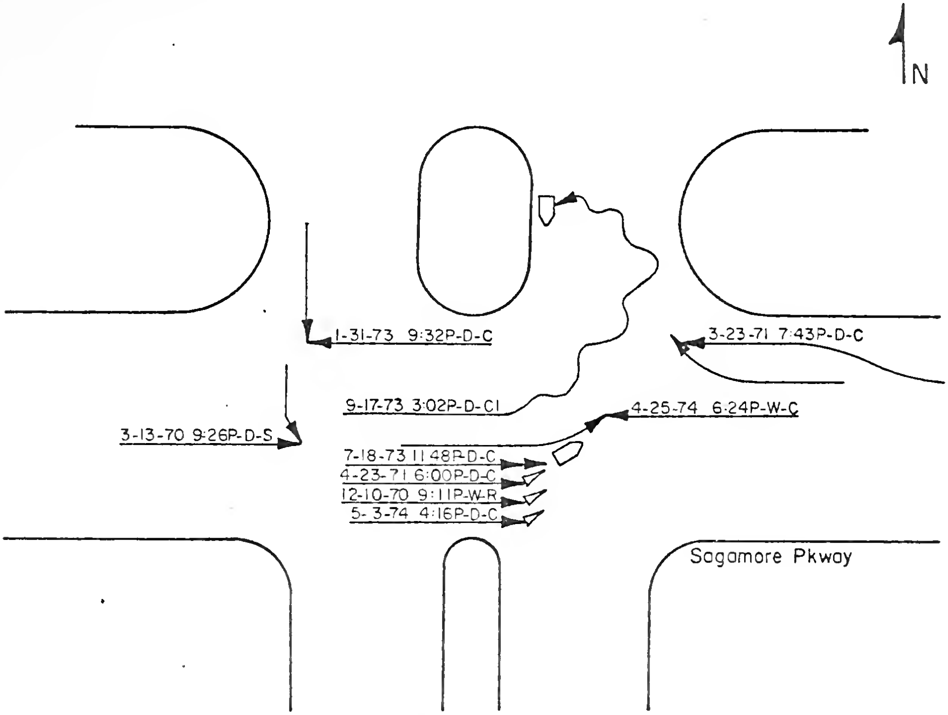
Four sites of this type (see Figure 36) were found, three of these on a two-lane highway where the openings lead into a subdivision. As would be expected on a two-lane highway, vehicles making a left-turn off the highway were involved in several rear-end accidents at each site as they waited for a gap in opposing traffic. The same pattern was apparent where the LSR terminated to form a three-legged highway intersection (see Figure 37).

It is interesting to note that for this two-lane section of highway, there were no accidents involving vehicles entering the highway from the LSR access points on the one side of the road, whereas on the opposite side with direct driveways there was an accident involving a vehicle backing from a residential driveway onto the highway. In fact, at this same private drive another accident involving a rear-end collision of a left-turning vehicle was recorded.

COLLISION DIAGRAM and TABULAR SUMMARY

City West Lafayette Period: from Jan. 1, 1970 to June 30, 1974

Location 500 W. Sagamore Pkwy (US 52 Bypass) @ University Square drive



TYPE		TOTAL PI	PD	FA	ALL
Right Angle		1	2		3
Rear End			4		4
Head On					
Side Swipe:	Opp. Dir.				
	Same Dir.				
Wrong Lane:	Lt. Turn				
	Rt. Turn		1		1
Correct Lane	Lt. Turn				
	Rt. Turn				
Fixed Object					
Out-of-Control			1		1
Pedestrian					
U-Turn					
Other					
TOTAL		1	8		9

Date Compiled June 1974

Traffic Controls None

Data Source WLPD

Analyst C. Baughman

Figure 35. Collision Diagram for Site 01 on the Highway

Figure 36. A Typical Three-Legged Highway Intersection at a Local Service Road Access Point

Figure 37. A Three-Legged Highway Intersection Where a Local Service Road Terminates

The fourth intersection of this type, on a four-lane divided highway, had no accident history.

Highway Intersection at LSR Access Point, No Median Crossover - Type G (see Figure 3)

Six locations of this design (see Figure 38) were investigated for their accident experience. Three of these, all with comparatively low volumes, exhibited no accident history. Of the other three that did, one had been altered during the study period from a four-legged intersection with median crossover, thus presenting an opportunity for comparison of an open median with a closed median.

The before-closure history (see Figure 39),covering a study period of three years, revealed five accidents involving vehicles entering the highway. Two of these rear-end collisions involved vehicles on the access approach turning right; another was a right-angle collision of a left-turning vehicle with far-side highway thru traffic; and two were sideswipe collisions in the crossover(one in wet weather) with vehicles coming from the other driveway. Two other pre-closure accidents involved vehicles exiting the highway, one a multiple-vehicle rear-end collision in which the lead vehicle slowed for a left-turn, the other a right angle collision of a right-turn vehicle with a driveway vehicle preparing to cross the median.

In contrast, the after-closure history of one and one-half years revealed only two accidents (see Figure 40), both in rainy weather involving vehicles entering the highway. One was a rear-end collision of right-turn vehicles on the access drive and the other a sideswipe collision of a thru vehicle and an entering right-turn vehicle. An effective reduction of nearly two accidents per year has occurred at this access location since the closing of the median. Clearly the median treatment is an important consideration when coordinated with LSR access points.

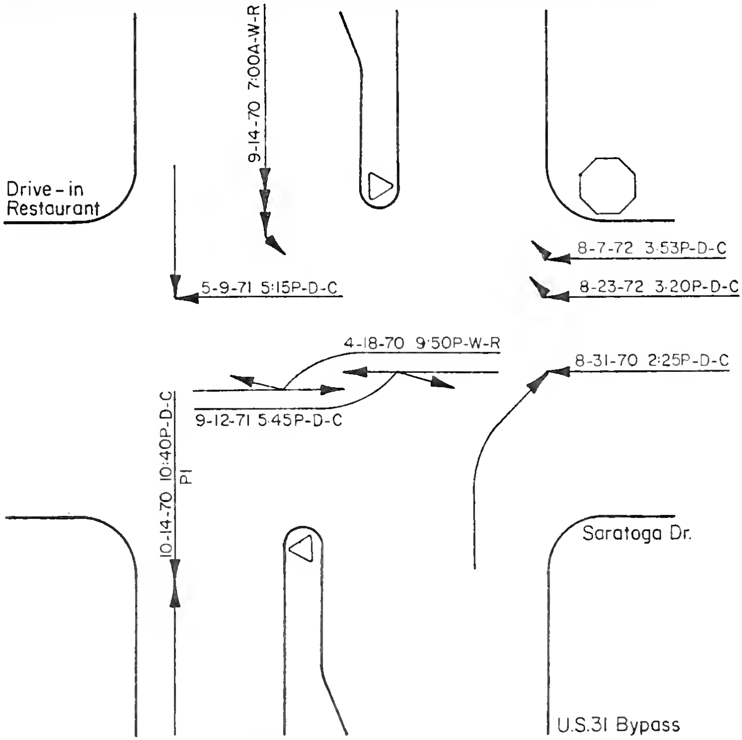
At the other two no-crossover locations, only two and one accidents were found to occur over the four and one-half year study period. The two at the site shown in Figure 38 both occurred on the highway, one a

Figure 38. A Typical Highway Intersection Where the Local Service Road Access Point Has No Median Crossover

COLLISION DIAGRAM and TABULAR SUMMARY

City Kokomo Period: from Jan. 1, 1970 to Dec. 31, 1972

Location 1520 S. US 31 Bypass @ Saratoga Drive (with crossover)



TYPE	TOTAL PI	TOTAL PD	TOTAL FA	TOTAL ALL
Right Angle		2		2
Rear End		5		5
Head On	1			1
Side Swipe: Opp. Dir.		2		2
Same Dir.				
Wrong Lane: Lt. Turn				
Rt. Turn				
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control				
Pedestrian				
U-Turn				
Other				
TOTAL	1	9		10

Date Compiled August 1974

Traffic Controls YIELD, STOP signs

Data Source Kokomo PD

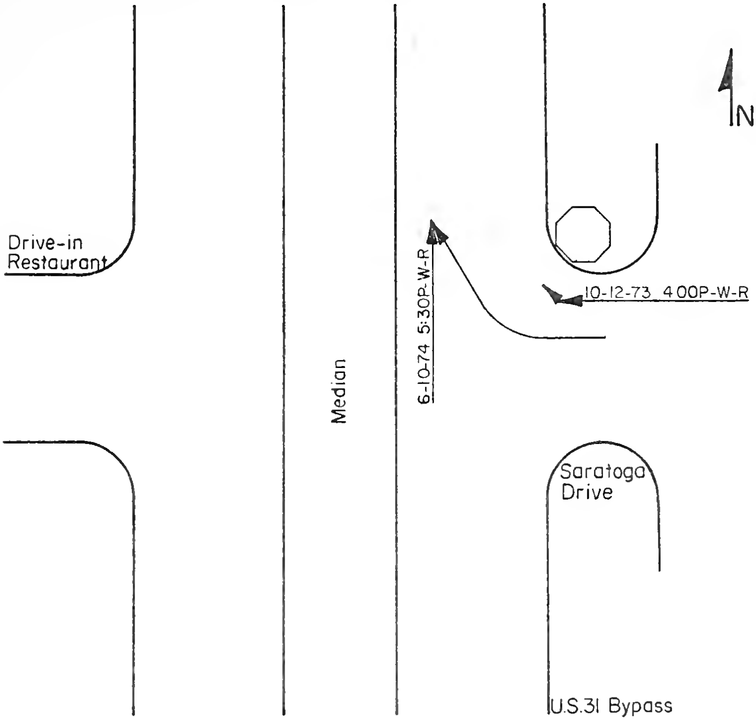
Analyst C. Baughman

Figure 39. Collision Diagram for Site 15 Previous to Closure of the Median

COLLISION DIAGRAM and TABULAR SUMMARY

City Kokomo Period: from Jan. 1, 1973 to June 30, 1974

Location 1520 S. US 31 Bypass @ Saratoga Drive (crossover blocked)



TYPE	TOTAL PI	PD	FA	ALL
Right Angle				
Rear End		1		1
Head On		1		1
Side Swipe: Opp. Dir.				
Same Dir.				
Wrong Lane: Lt. Turn				
Rt. Turn				
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control				
Pedestrian				
U-Turn				
Other				
TOTAL		2		2

Date Compiled August 1974

Traffic Controls STOP sign

Data Source Kokomo PD

Analyst C. Baughman

Figure 40. After-Closure Collision Diagram for Site 15

rear-end collision headed by an exiting right-turn vehicle, a movement indicated as hazardous by the conflicts count, and the other a sideswipe collision of a thru-vehicle with an entering right-turn vehicle. The exiting right turn problem (19 conflicts per 46 right turns from the ten-hour conflicts study) would suggest a right-turn lane at this opening, even though the percent of right-turns is only 1.5.

The one recorded accident at the final Type G site was a right-angle collision of a highway vehicle exiting by a right turn with a sideroad vehicle waiting to enter the highway. The exiting vehicle apparently turned wide, a maneuver which again might have been eliminated by a right turn lane.

Four-Legged Highway Intersection at LSR Terminus - Type H (see Figure 3)

Six sites of this type were reviewed for accident experience, five of these with the LSR terminating at the crossroad and the other one with the LSR terminating at the highway intersection. At one of the four-legged crossroad intersections an LSR terminated at the crossroad on both sides of the highway.

LSR Terminating at the Crossroad (see Figure 41). A four-legged highway intersection at a low volume residential street exhibited only one accident, a sideswipe due to an attempted left turn from the outside lane, even though a left-turn lane was present.

The four-legged location where an LSR on each side of the highway terminates at the same crossroad experienced no accidents, both LSR's receiving little use. On a lower volume crossroad at the other end of one of these LSR's, one rear-end accident of two vehicles approaching the highway was recorded. The width of outer separation at these low volume locations, ranging from twenty to fifty feet, does not appear to be crucial.

Another crossroad intersection had a low volume LSR terminating at the crossroad adjacent to a signalized highway intersection. As would be expected, most of the accidents at this location were rear-end collisions on the highway (see Figure 42); the very few involving crossroad vehicles were mainly right-angle collisions on the approach opposite the LSR side. The LSR appeared to be of sufficiently low volume to not in-

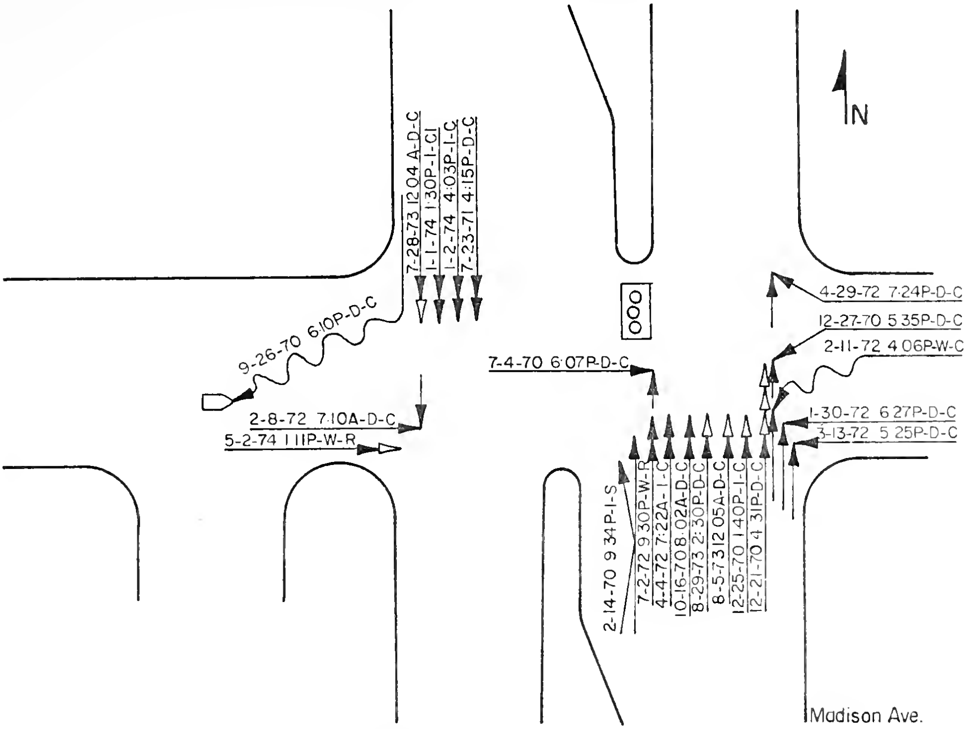
Figure 41. A Typical Four-Legged Highway Intersection, the Fourth Leg to the Left of the Picture, Where an LSR Terminates at the Crossroad

Figure 45. At this Site the Local Service Road Terminates at a Highway Intersection

COLLISION DIAGRAM and TABULAR SUMMARY

City Indianapolis Period: from Jan. 1, 1970 to June 30, 1974

Location 6500 S. Madison Ave. (SR 431) @ Banta Road



TYPE	TOTAL PI	PD	FA	ALL
Right Angle	3	3		6
Rear End	4	10		14
Head On				
Side Swipe: Opp. Dir.				
Same Dir.				
Wrong Lane: Lt. Turn				
Rt. Turn				
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control	1	1		2
Pedestrian				
U-Turn				
Other				
TOTAL	8	14		22

Date Compiled October 1974

Traffic Controls Signal

Data Source Marion Co. Sheriff

Analyst C. Baughman

Figure 42. Collision Diagram for Site 25 on the Highway

crease the hazard of the highway intersection, even though it is separated from the highway by only twenty feet.

A highway intersection where both the crossroad and the LSR are comparatively well-used experienced mostly right angle collisions of vehicles entering the highway via left turns (see Figure 43)--two with the near-side highway traffic and two with the far-side traffic. The other accidents at this intersection were right angle collisions of crossroad vehicles as they moved across the highway from the opposite approach toward the LSR side. As the intersection was an important commercial and apartment driveway, the number of accidents was not felt to be unusual.

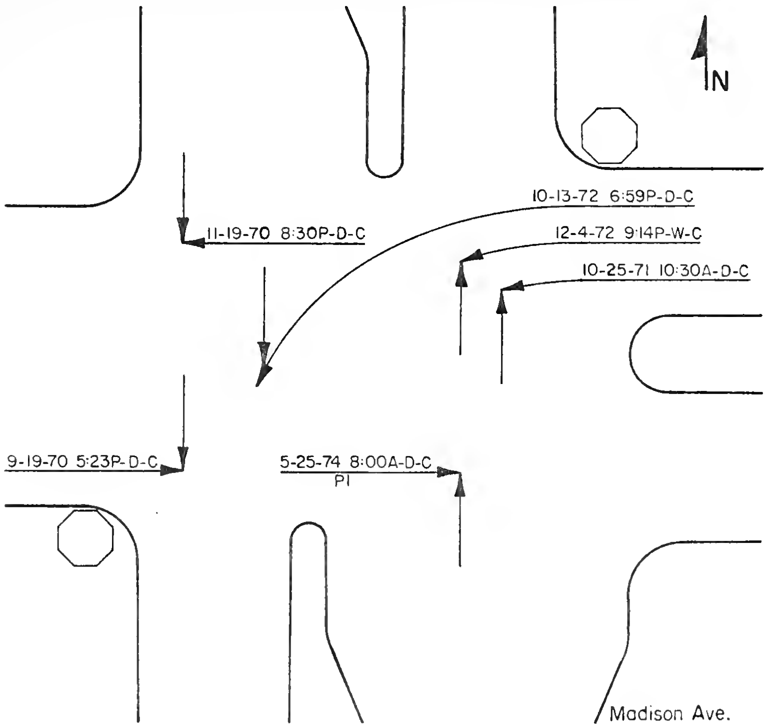
A final highway intersection, where the crossroad approach on the LSR side handles mostly service road traffic, exhibited two accidents. One was a three-car rear-end collision started by a vehicle turning (see Figure 44) right into the service road; the other involved a right-turn vehicle which lost control as it swerved into the service road. The low angle of diverge of the service road appeared to invite unacceptably high speeds of exit from the highway and consequential encroachment on the opposing lane of the LSR, creating hazard for drivers both entering the service road and leaving it. A proper design for this location would have provided for the service road to terminate at the highway and not an existing road or drive.

LSR Terminus at the Highway Intersection (see Figure 45). At the one location found where a service road terminal point forms a four-legged STOP-controlled intersection with a divided highway, the road opposite the LSR approach is a business route toward town. Accidents to vehicles using this intersection totaled four over the one and one-half year period of available records (see Figure 46). All of these accidents involved vehicles entering the highway from the business route opposite the service road approach. Three of these were rear-end collisions in the crossover in which the rear vehicle proceeded to cross the near-side highway traffic, thinking the lead vehicle would move ahead onto the highway.

COLLISION DIAGRAM and TABULAR SUMMARY

City Indianapolis Period: from Jan. 1, 1970 to June 30, 1974

Location 8100 S. Madison Ave. (SR 431) @ Creston Village Square Driveway



TYPE	TOTAL PI	PD	FA	ALL
Right Angle	1	4		5
Rear End		1		1
Head On				
Side Swipe: Opp. Dir.				
Same Dir.				
Wrong Lane: Lt. Turn				
Rt. Turn				
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control				
Pedestrian				
U-Turn				
Other				
TOTAL	1	5		6

Date Compiled October 1974

Traffic Controls STOP signs

Data Source Marion Co. Sheriff

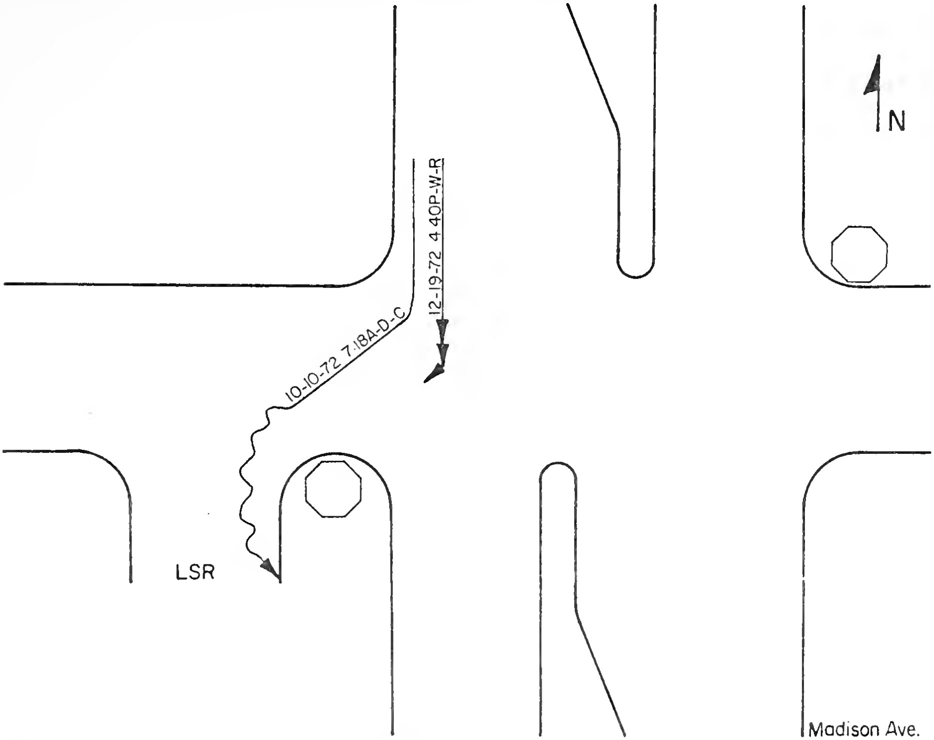
Analyst C. Baughman

Figure 43. Collision Diagram for Site 23

COLLISION DIAGRAM and TABULAR SUMMARY

City Indianapolis Period: from Jan. 1, 1970 to June 30, 1974

Location 5050 S. Madison Ave. (SR 431) at Northern Terminus of LSR



TYPE	TOTAL			
	PI	PD	FA	ALL
Right Angle		1		1
Rear End		1		1
Head On				
Side Swipe: Opp. Dir.				
Same Dir.				
Wrong Lane: Lt. Turn				
Rt. Turn				
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control				
Pedestrian				
U-Turn				
Other				
TOTAL		2		2

Date Compiled October 1974

Traffic Controls STOP sign

Data Source Marion Co. Sheriff

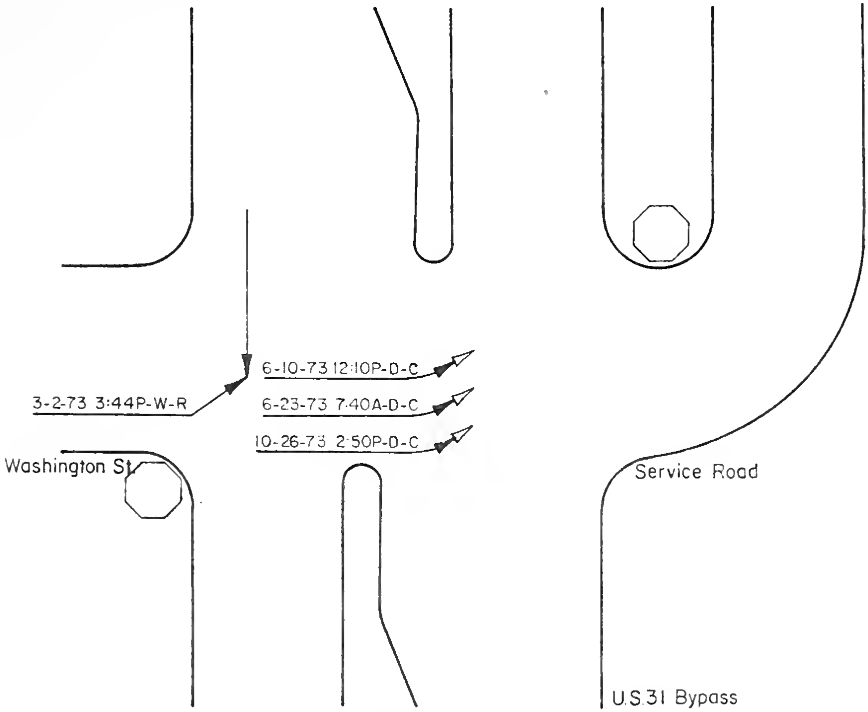
Analyst C. Baughman

Figure 44. Collision Diagram for Site 05

COLLISION DIAGRAM and TABULAR SUMMARY

City Kokomo Period: from Jan. 1, 1973 to June 30, 1974

Location US 31 Bypass @ Washington St. LSR



TYPE	TOTAL			
	PI	PD	FA	ALL
Right Angle		1		1
Rear End		3		3
Head On				
Side Swipe: Opp. Dir.				
Same Dir.				
Wrong Lane: Lt. Turn				
Rt. Turn				
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control				
Pedestrian				
U-Turn				
Other				
TOTAL		4		4

Date Compiled April 1975

Traffic Controls STOP signs

Data Source Howard Co. Hwy. Dept.

Analyst C. Baughman

Figure 46. Collision Diagram for an LSR Terminus at a Highway Intersection

Low-Angle Diverge with Three-Legged Intersection Beyond - Type I (see Figure 3)

One location of this design was found (see Figure 47) with the accident history available for only the last year-and-a-half of the desired study period. The exit lane enters into a three-legged intersection about thirty feet beyond the highway, thus this intersection deserves study also as it is inextricably related to the operation of the ramp.

One accident was found to occur on the main highway at the diverge point. A driver who was slowing down in the left lane was struck in the rear as he crossed the right lane toward the exit. It is felt that nothing in the way of design or operational practice can prevent such an incident; perhaps the rainy conditions of the time was a primary contributor. Fortunately there were no accidents recorded involving a wrong-way maneuver from the local streets into the exit lane. Apparently, the signing (see Figure 48) has been effective, but the potential for a serious wrong-way accident remains.

At the three-way intersection, where the exit lane becomes a two-way roadway, five accidents were recorded (see Figure 49). Two of these involved vehicles coming from the highway colliding at right angles with vehicles turning from the side street on the right. As illustrated in the picture, the visibility of high-speed vehicles coming around the highway bend into the LSR is not good. The other three collisions involved opposing vehicles making the sharp turns required by the design and signing. A contributing factor here seems to be the small turning radius required for the right turn onto the LSR.

Case Study Comparisons: Locations With and Without LSR

Suitable locations allowing for accident comparison of sites with and without LSR's were two in number,one a pair of sections on a four-lane highway with median (Madison Ave., SR 431 in Indianapolis), the other a two-lane highway (Sagamore Pkwy, US 52 in West Lafayette). In addition, a conflicts comparison was made for the four-lane highway locations.

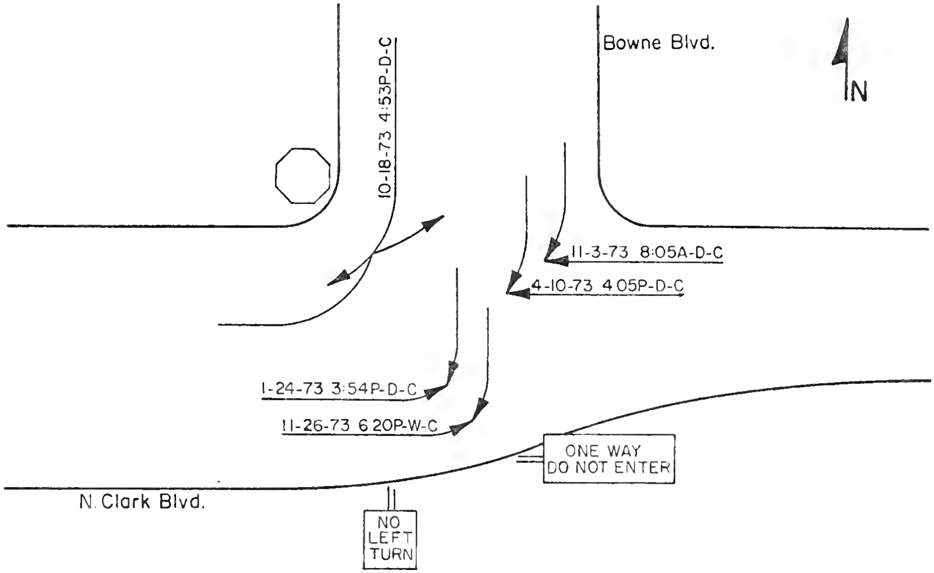
Figure 47. A Low-Angle Diverge Point of Entrance into a Service Road

Figure 48. This Three-Legged Street Intersection Is Located Too Near the Point of Divergence from the Highway

COLLISION DIAGRAM and TABULAR SUMMARY

City Clarksville Period: from Jan. 1, 1973 to June 30, 1974

Location N. Clark Blvd. @ Bowne Blvd., just beyond exit from highway



TYPE		TOTAL			
		PI	PD	FA	ALL
Right Angle			4		4
Rear End					
Head On					
Side Swipe:	Opp. Dir.		1		1
	Same Dir.				
Wrong Lane:	Lt. Turn				
	Rt. Turn				
Correct Lane	Lt. Turn				
	Rt. Turn				
Fixed Object					
Out-of-Control					
Pedestrian					
U-Turn					
Other					
TOTAL			5		5

Date Compiled August 1974

Traffic Controls STOP, NO LEFT TURN, ONE WAY DO NOT ENTER

Data Source Clarksville Police

Analyst C. Baughman

Figure 49. Collision Diagram for an Intersection Beyond a Highway Diverge

Four-Lane Case Study Comparison

The two sections of Madison Ave. in Indianapolis were used primarily on the basis of similar land uses (see Figures 50 and 51). The site without the LSR exhibited somewhat higher roadside use due to the presence of apartments. Table 12 shows the volume of in and out traffic detected during the ten hour conflicts count for the driveways at each section, as well as the number of accidents for each driveway in the four and one-half year accident study period.

Table 12. Roadside Traffic Volume and Accidents Counted at Madison Avenue Locations

Driveway Identification		a	b	c	d	e	f	g	h	i	j	k	Total
Without LSR	In	6	10	31	14	52	5	11	156	12	3	0	300
	#Accs	0	0	2	0	0	0	0	1	1	0	0	4
	Out	8	16	27	7	36	3	0	115	20	12	2	246
	#Accs	0	0	1	0	0	0	0	14	0	0	0	15
With LSR	In	72	77	12	28	63	-	-	-	-	-	-	252
	#Accs	2	4+	0	6	1	-	-	-	-	-	-	13
	Out	12	87	24	16	72	-	-	-	-	-	-	211
	#Accs	0	2+	1*	1*	1*	-	-	-	-	-	-	5

*Accidents occurred at LSR intersection

+One accident occurred at LSR intersection, others occurred at highway intersection

At first glance, it would appear that the non-LSR section is no more hazardous than the LSR location. However, many of the accidents at both locations can be traced to unique features of their designs. Let us now look at the patterns and how engineering changes might be able to improve both situations.

Of the four accidents involving vehicles going into non-LSR driveways, three were from left-turn maneuvers all made at locations where no left-turn lane exists, immediately suggesting an improvement in this manner. The other was a rear-end accident involving a right-turning vehicle exiting the highway.

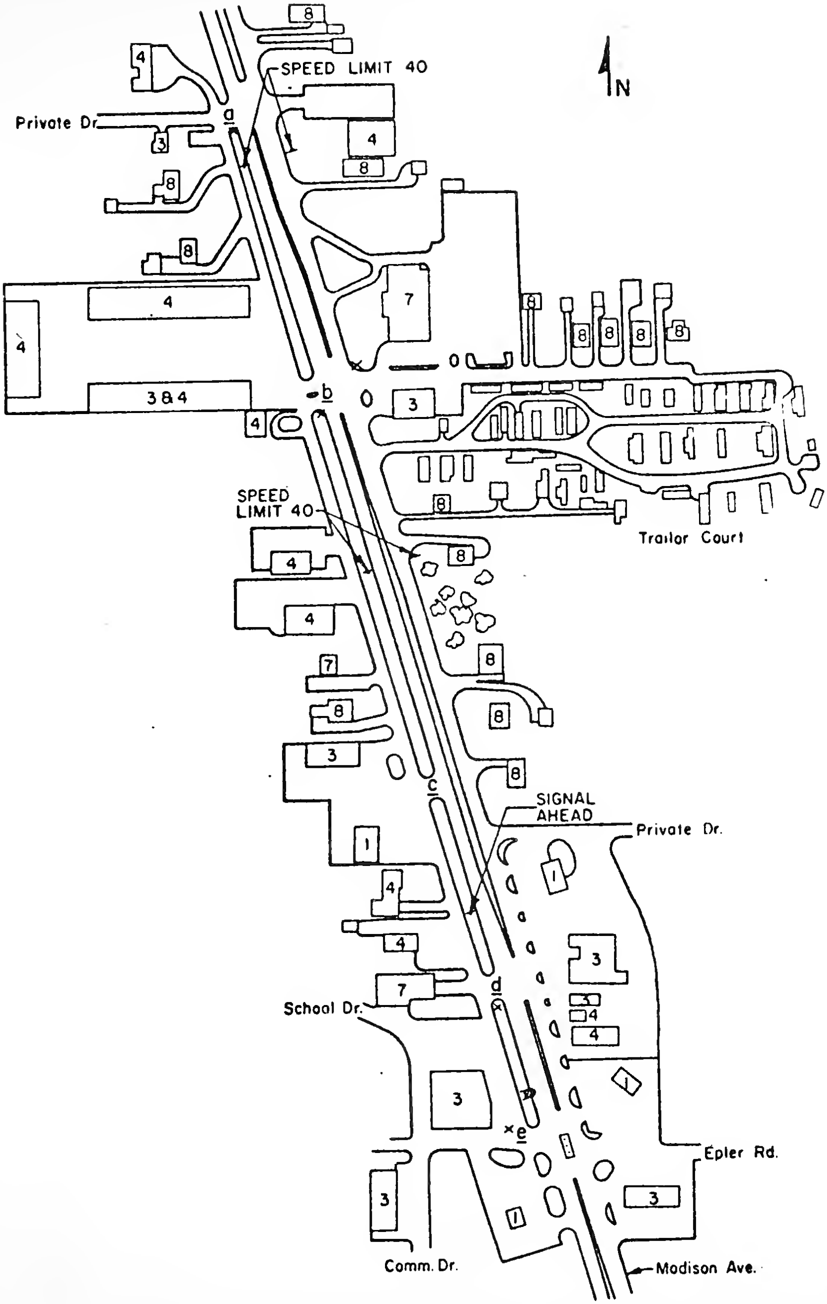


Figure 50. A Four-Lane Highway with an LSR, Showing the Driveways Studied (5050-5500 Madison Ave., Indianapolis)

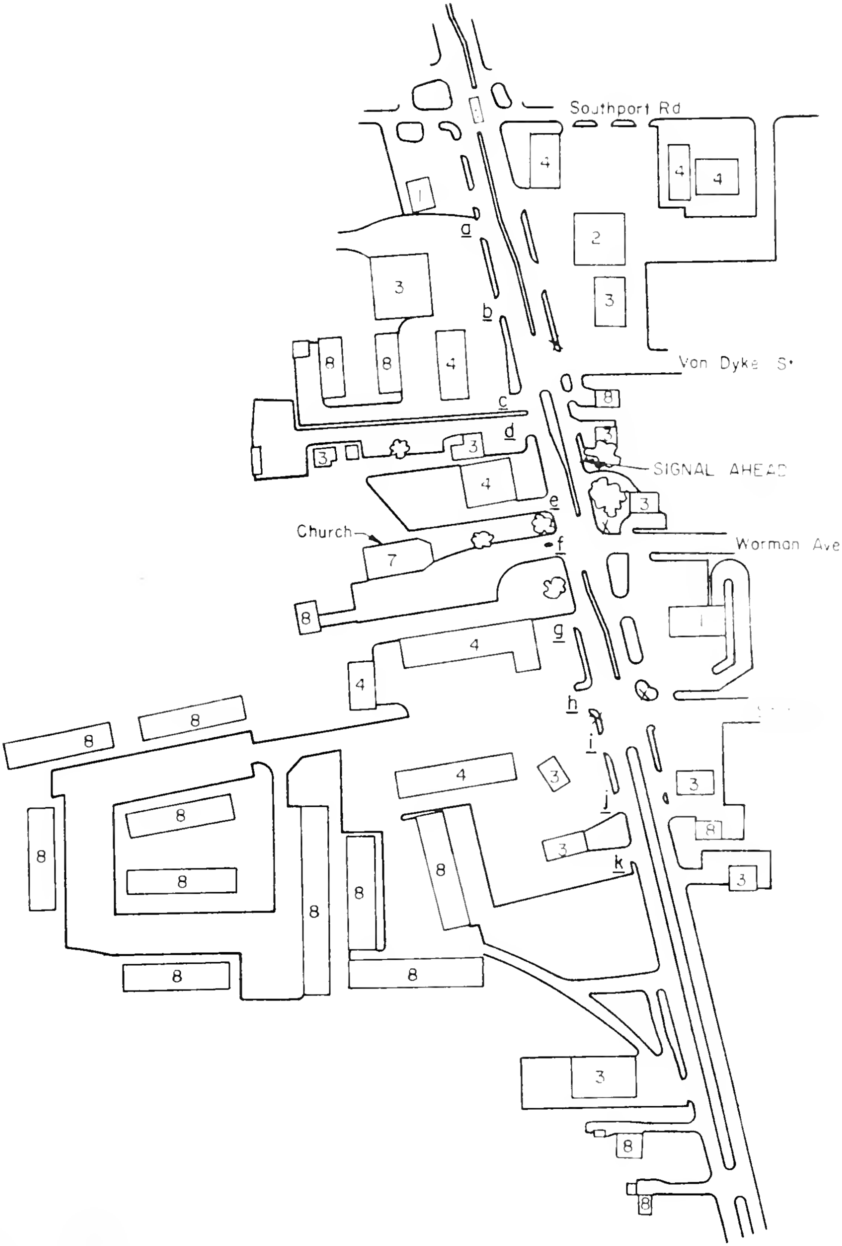


Figure 51. A Four-Lane Highway Without an LSR, Showing the Driveways Studied (7020-7440 Madison Ave., Indianapolis)

With regard to accidents of non-LSR traffic entering the highway, fourteen of these were right-angle accidents at the same location (see Figure 52), eleven involving vehicles making a left turn to go north. Three of these eleven collisions were with southbound thru traffic, two collided with southbound left-turn traffic, and six collided with northbound thru traffic. These six represent nearly half of the total of fourteen collisions to entering vehicles at this location. An on-site inspection of the intersection revealed a poorly located side street placement with respect to the median opening as shown in Figure 53. Note how the median curbing consequently restricts the turning radius of the left turn onto the highway, forcing such vehicles into the right lane. Most of these six collisions could have been avoided by proper placement of the side street.

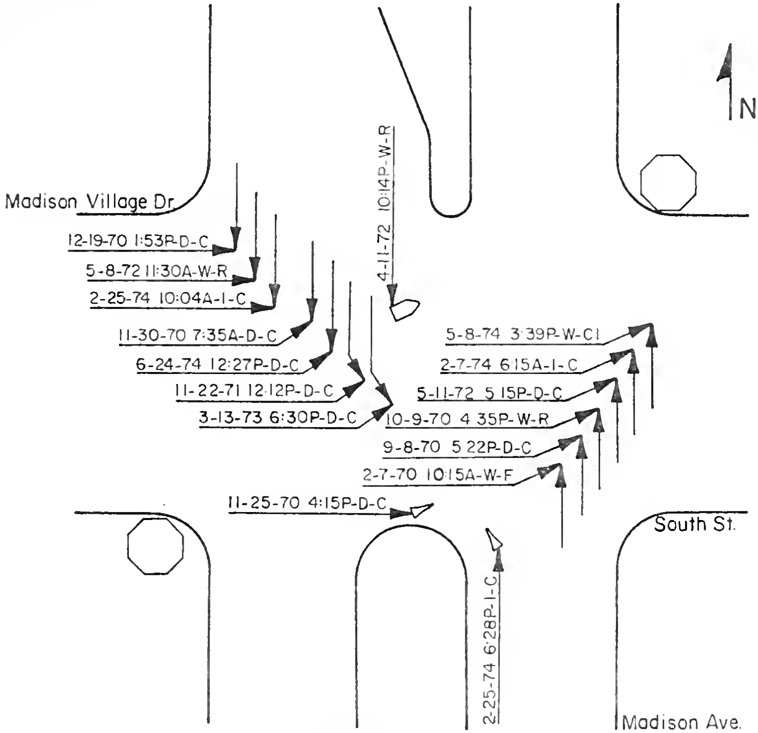
An additional pair of retail stores to the south of this study site are indirectly served by a residential driveway crossover without left-turn lanes in either direction, located about one-hundred-fifty feet south of the driveway. At this site were found four rear-end collisions, three with personal injury, involving southbound vehicles slowing for a U-turn (see Figure 54). These could likely have been prevented by a protected left-turn lane, but one other accident involved a vehicle going northward crossing the median opening and traveling the wrong way in the southbound lane to get to the stores' driveway, colliding at right angles with a vehicle exiting that drive. Dangerous situations such as these U-turns and wrong way maneuvers could very well be eliminated by coordination of median openings and service road access points. Such coordination could also prevent the irresponsible placement of direct driveways and their associated hazards.

Turning now to the LSR location, it appears that most of the problem is with vehicles entering the service road. Recall that the six accidents at access location "d" are rear-end collisions involving waiting left-turn vehicles where no left-turn lane exists for this median crossover opening two hundred feet beyond a traffic signal. Of the other seven in-movement accidents, four were rear-end collisions arising from right-turning vehicles, again suggesting a turning lane. Two other entering accidents occurred at LSR intersections, both at Type B sites, where a

COLLISION DIAGRAM and TABULAR SUMMARY

City Indianapolis Period: from Jan. 1, 1970 to June 30, 1974

Location 7200 S. Madison Ave. (SR 431) @ Madison Village Drive



TYPE	TOTAL			
	PI	PD	FA	ALL
Right Angle	4	10		14
Rear End		2		2
Head On				
Side Swipe: Opp. Dir.				
Same Dir.				
Wrong Lane: Lt. Turn				
Rt. Turn				
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control				
Pedestrian				
U-Turn				
Other				
TOTAL	4	12		16

Date Compiled October 1974

Traffic Controls STOP signs

Data Source Marion Co. Sheriff

Analyst C. Baughman

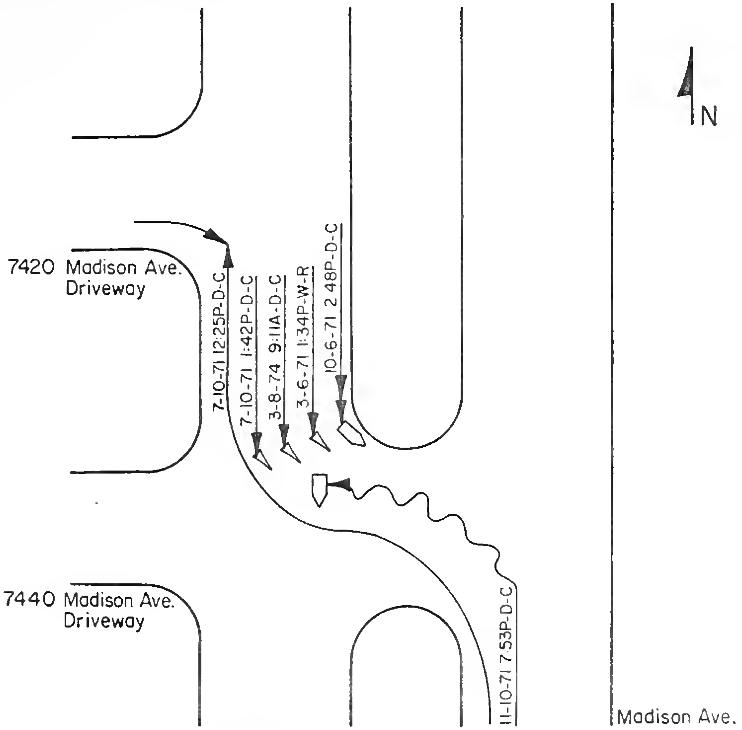
Figure 52. Collision Diagram for Drive "H" of Figure 51

Figure 53. Left-Turns from this Street into the Arterial Are Difficult Due to Poor Location with Respect to the Median

COLLISION DIAGRAM and TABULAR SUMMARY

City Indianapolis Period: from Jan. 1, 1970 to June 30, 1974

Location 7440 S. Madison Ave. (SR 431) @ residential crossover



TYPE	TOTAL PI	PD	FA	ALL
Right Angle		1		1
Rear End	3	1		4
Head On	1			1
Side Swipe: Opp. Dir.				
Same Dir.				
Wrong Lane: Lt. Turn				
Rt. Turn				
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control				
Pedestrian				
U-Turn				
Other				
TOTAL	4	2		6

Date Compiled October 1974

Traffic Controls None

Data Source Marion Co. Sheriff

Analyst C. Baughman

Figure 54. Collision Diagram for a Median Crossover

right-turning or thru crossroad vehicle collided with an LSR vehicle.

Of the five accidents involving vehicles leaving the service road, three occurred on the service road at points of access to the highway, all right-angle collisions at Type B sites. The other two were right-angle collisions of left-turning vehicles with far side highway traffic. This type of accident was fairly common for exiting LSR vehicles, and would suggest a wider median allowing vehicles to enter or cross the highway one direction at a time. The difficulty of the Type B LSR intersection with both in- and out-movements suggests that such intersections, being adjacent to the highway as they are, should be avoided whenever possible in LSR design, especially at commercial locations such as this.

Tables 13 and 14 are conflicts comparisons for the highway traffic on the two sections. Again, as in all data analysis only movements using the drives on the side of the highway of interest were considered, thus the description of turning movement type indicates some empty cells. The observed data for each section is presented for both approaches in Table 13, then in Table 14 the without LSR data is adjusted to LSR volumes for ease of comparison. It appears that the non-LSR sections pose greater potential hazard to traffic movements both entering and exiting from the highway.

Two-Lane Case Study Comparison

Two sections of the US 52 Bypass in West Lafayette were used in this comparison. Both sections have experienced some additional development since the beginning of the study period, but at a fairly even pace, thus this is not a factor. For the land uses as of mid-1974 see Figures 55 and 56. As conflicts counts were not made for these sections, no direct information is known about the driveway volumes, but estimation of daily traffic made on the basis of trip generation studies (8, 28, 40) and interviews indicated the similarity in sections. These estimates for each driveway and the number of accidents found at each are summarized in Table 15.

Table 13. Conflicts Comparison, Madison Ave. (SR 431) at Locations With and Without a Local Service Road

Traffic Movement	Approach No.	Turning Movement Type 1	Turning Movement Type 2	Without LSR, 11 points of access 1	Without LSR, 11 points of access 2	With LSR, 5 points of access 1	With LSR, 5 points of access 2
Weave	No. Vehicles	any turn	any turn	35	35	11	14
	No. Conflicts			2	1	0	0
	Confs./Veh.			0.057	0.029	0	0
Opposing left-turn	No. Vehs.	exit hwy.	-	81		80	
	No. Confs.			2		0	
	Confs./Veh.			0.025		0	
Thru X-traffic Left to Right	No. Vehs.	exit hwy.	enter hwy.	14	24	8	6
	No. Confs.			0	0	0	0
	Confs./Veh.			0	0	0	0
Thru X-traffic Right to Left	No. Vehs.	enter hwy.	exit hwy.	24	6	3	2
	No. Confs.			2	0	0	0
	Confs./Veh.			0.083	0	0	0
Lt-turn X-traffic from left	No. Vehs.	-	enter hwy.		108		91
	No. Confs.				12		0
	Confs./Veh.				0.110		0
Lt-turn X-traffic from right	No. Vehs.	enter hwy.	-	93		86	
	No. Confs.			2		0	
	Confs./Veh.			0.022		0	
Rt-turn X-traffic from right	No. Vehs.	enter hwy.	-	108		123	
	No. Confs.			6		1	
	Confs./Veh.			0.056		0.008	
Left-turn approach traffic	No. Vehs.	-	exit hwy.		73		106
	No. Confs.				15		10
	Confs./Veh.				0.206		0.094
Right-turn approach traffic	No. Vehs.	exit hwy.	-	201		152	
	No. Confs.			43		23	
	Confs./Veh.			0.214		0.151	

Table 14. Conflicts Comparison, Madison Ave. (SR 431) at Locations With and Without a Local Service Road, With Non-LSR Data Adjusted to LSR Volumes

		Turning Movement Type		Non-LSR, Adjusted to LSR	With LSR	Non-LSR, Adjusted to LSR	With LSR
Traffic Movement	Approach No.	1	2	1	1	2	2
Weave	No. Vehs. No. Confs. Confs./Veh.	any turn	any turn	11 1 0.091	11 0 0	14 0 0	14 0 0
Opposing Left-turn	No. Vehs. No. Confs. Confs./Veh.	exit hwy.	-	80 2 0.025	80 0 0		
Thru X-traffic Left to Right	No. Vehs. No. Confs. Confs./Veh.	exit hwy.	enter hwy.	8 0 0	8 0 0	6 0 0	6 0 0
Thru X-traffic Right to Left	No. Vehs. No. Confs. Confs./Veh.	enter hwy.	exit hwy.	3 0 0	3 0 0	2 0 0	2 0 0
Lt-turn X-traffic from left	No. Vehs. No. Confs. Confs./Veh.	-	enter hwy.			91 10 0.110	91 0 0
Lt-turn X-traffic from right	No. Vehs. No. Confs. Confs./Veh.	enter hwy.	-	86 2 0.022	86 0 0		
Rt-turn X-traffic from right	No. Vehs. No. Confs. Confs./Veh.	enter hwy.	-	123 7 0.056	123 1 0.008		
Left-turn approach traffic	No. Vehs. No. Confs. Confs./Veh.	-	exit hwy.			106 22 0.206	106 10 0.094
Right-turn approach traffic	No. Vehs. No. Confs. Confs./Veh.	exit hwy.	-	152 33 0.214	152 23 0.151		

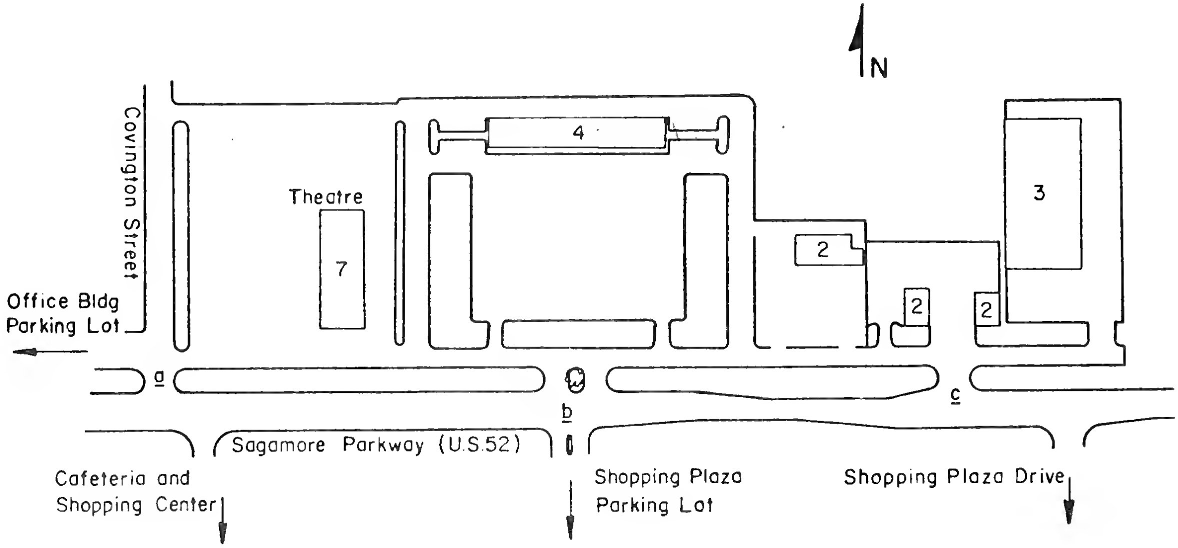


Figure 55. A Two-Lane Highway With an LSR, Showing the Driveways Studied (300-510 Sagamore Pkwy., West Lafayette)

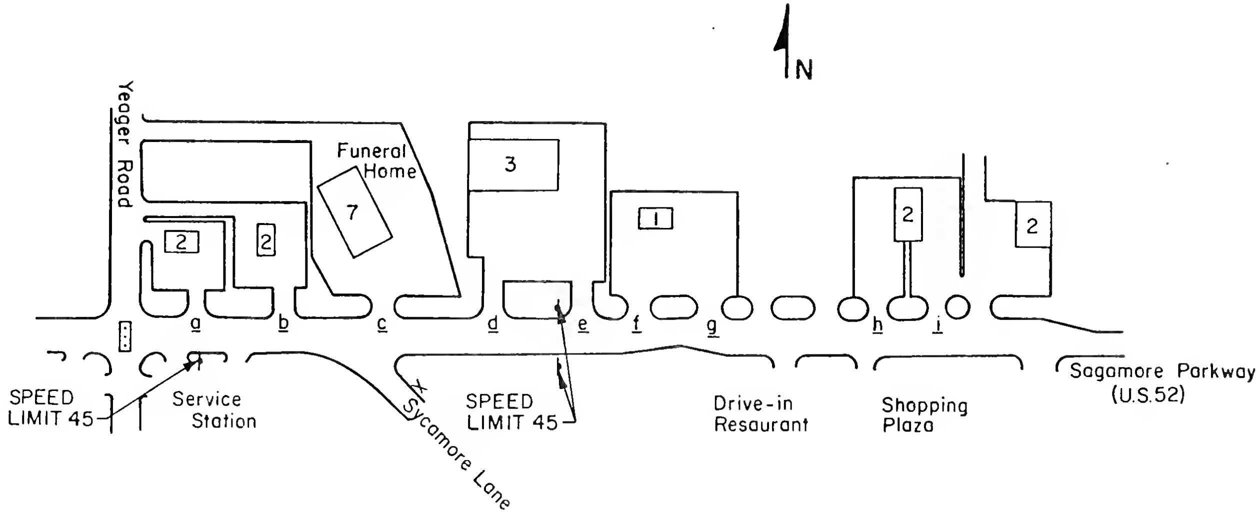


Figure 56. A Two-Lane Highway Without an LSR, Showing the Driveways Studied (1070-1200 Sagamore Pkwy., West Lafayette)

Table 15. Estimated Roadside Traffic Volume and Actual Accidents Counted for US 52 Bypass Locations

Driveway Identification		a	b	c	d	e	f	g	h	i	Total
Without LSR	In	190	25	10	25	30	37	38	100	100	555
	#Accs	0	0	2	1	0	0	1	2	1	7
	Out	190	25	10	30	25	38	27	100	100	555
	#Accs	4	0	0	0	0	0	0	0	0	4
With LSR	In	50+	275	200	-	-	-	-	-	-	525
	#Accs	0	6	1							7
	Out	50+	275	200	-	-	-	-	-	-	525
	#Accs	0	2	0	-	-	-	-	-	-	2

+LSR traffic only, major portion of traffic entering highway comes from crossroad traffic

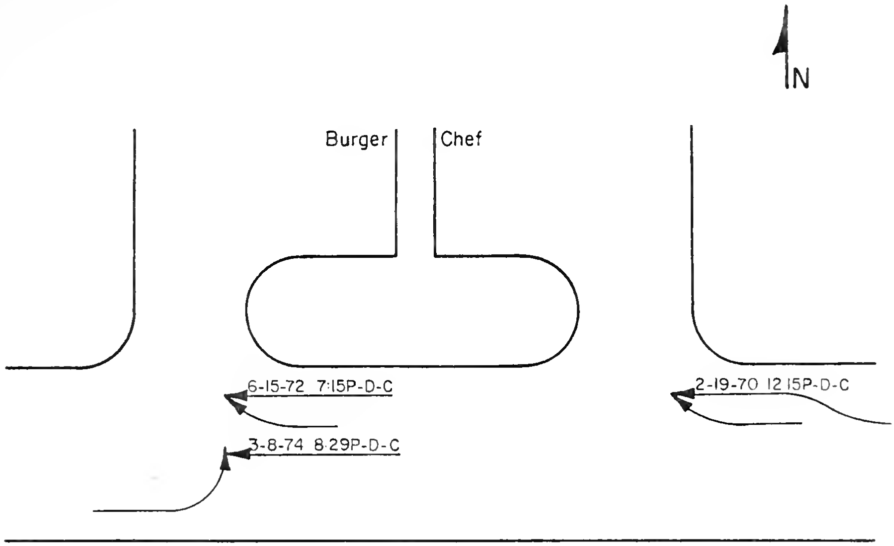
Again it would appear that the non-LSR site is no more hazardous than that with an LSR. For this two-lane case, in contrast to that of the four-lane case, the major portion of accidents at both locations comes from vehicles turning from the highway. This would be expected, there being no left turn protection on two-lane facilities. Following is a discussion of the accident patterns and possible means of improvement.

At the non-LSR location five of the seven mishaps of vehicles leaving the highway involved vehicles making a right turn from the wrong lane. A continuous right turn lane has been installed for the several driveways, but a tendency exists for drivers to use it as a lane for passing those slower vehicles which are in the next-to-center lane. When a center lane vehicle turns right, it collides with the vehicle passing in the right turn lane (see Figure 57). This problem could be somewhat improved by a four-lane highway, but improved performance could probably be achieved by better spacing of openings, such as for LSR access points, and sufficiently distinct right-turn lanes. One of the other non-LSR highway exiting accidents was a rear-end collision involving a left-turning vehicle. This type of accident is typically solved by left-turn lanes in the median. The remaining accident in this group was a right-angle collision of a vehicle turning left into the path of an oncoming vehicle.

COLLISION DIAGRAM and TABULAR SUMMARY

City West Lafayette Period: from Jan. 1, 1970 to June 30, 1974

Location 1082 Sagamore Parkway West (US 52 Bypass)



TYPE	TOTAL PI	PD	FA	ALL
Right Angle		1		1
Rear End				
Head On				
Side Swipe: Opp. Dir.				
Same Dir.				
Wrong Lane: Lt. Turn				
Rt. Turn		2		2
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control				
Pedestrian				
U-Turn				
Other				
TOTAL		3		3

Date Compiled March 1975

Traffic Controls None

Data Source West Lafayette PD

Analyst C. Baughman

Figure 57. Collision Diagram for Driveways "H" and "I" of Figure 56

The four accidents to vehicles entering the highway from drive "a" were all right-angle collisions with the near direction of traffic (see Figure 58). Some confusion might exist to this entering traffic of the intent of approaching and decelerating highway vehicles, especially if their right turn signals were activated, if they did not actually turn until a signalized intersection about 30 feet beyond drive "a. This would indicate the need for greater spacing between access locations to the highway.

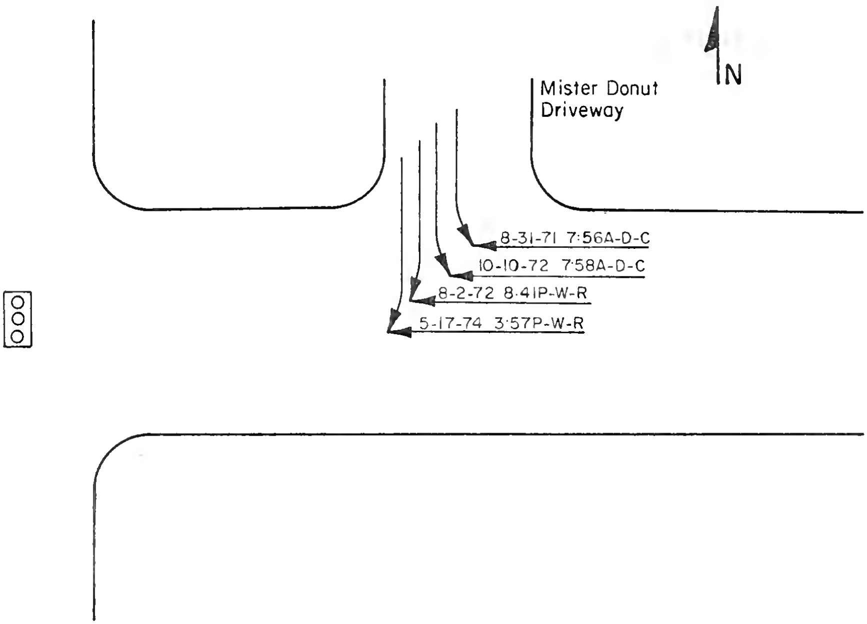
In contrast to the right-turn-from-wrong-lane accident pattern to vehicles exiting the highway in the non-LSR section, the pattern of exiting accidents at the LSR location was principally rear-end collisions to left-turning vehicles, of which there were four (see Figure 59). Two of the remaining exiting accidents were right-angle collisions of left-turning vehicles with opposing traffic, and the final one was a right-turn-from-wrong-lane type. Opportunity exists at this location for deceleration-passing confusion mentioned in the discussion of non-LSR accidents.

Both accidents involving vehicles entering the highway were at right angles with highway traffic, one with the near direction, the other with the far direction. Also, both occurred under night conditions. There appears to be little in the way of design that can prevent accidents such as these.

COLLISION DIAGRAM and TABULAR SUMMARY

City West Lafayette Period: from Jan. 1, 1970 to June 30, 1974

Location 1200 Sagamore Parkway West (US 52 Bypass)



TYPE	TOTAL			
	PI	PD	FA	ALL
Right Angle		4		4
Rear End				
Head On				
Side Swipe: Opp. Dir.				
Same Dir.				
Wrong Lane: Lt. Turn				
Rt. Turn				
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control				
Pedestrian				
U-Turn				
Other				
TOTAL		4		4

Date Compiled March 1975

Traffic Controls None

Data Source West Lafayette PD

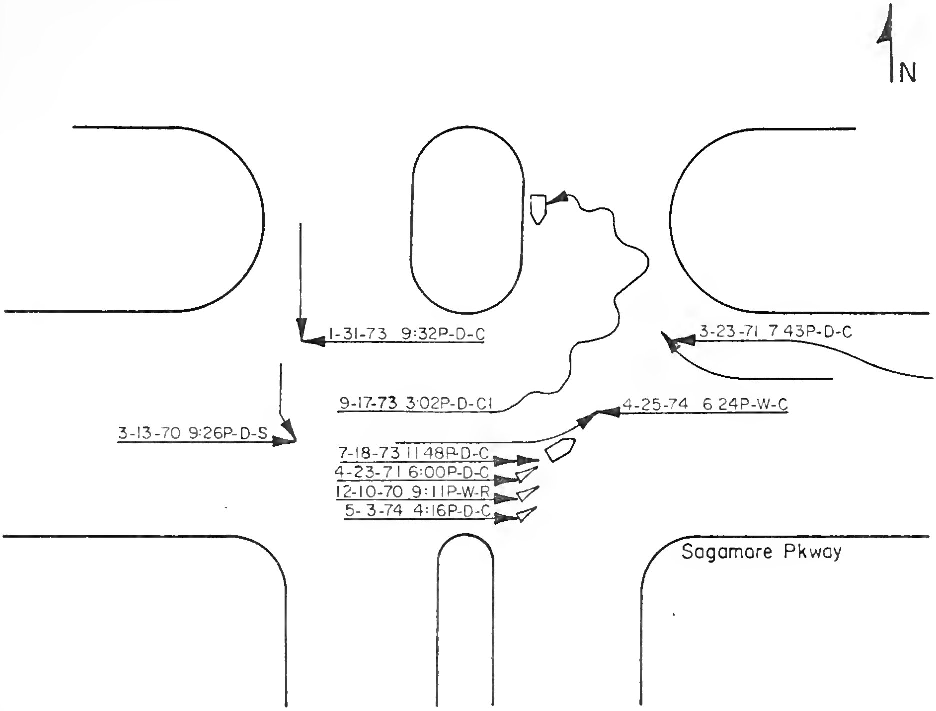
Analyst C. Baughman

Figure 58. Collision Diagram for Driveway "A" of Figure 56

COLLISION DIAGRAM and TABULAR SUMMARY

City West Lafayette Period: from Jan. 1, 1970 to June 30, 1974

Location 500 W. Sagamore Pkwy (US 52 Bypass) @ University Square drive



TYPE		TOTAL PI	PD	FA	ALL
Right Angle		1	2		3
Rear End			4		4
Head On					
Side Swipe:	Opp. Dir.				
	Same Dir.				
Wrong Lane:	Lt. Turn				
	Rt. Turn		1		1
Correct Lane	Lt. Turn				
	Rt. Turn				
Fixed Object					
Out-of-Control			1		1
Pedestrian					
U-Turn					
Other					
TOTAL		1	8		9

Date Compiled June 1974

Traffic Controls None

Data Source WLPD

Analyst C. Baughman

Figure 59. Collision Diagram for Driveway "B" of Figure 55

DEVELOPMENT OF RESULTS

Discussion of Service Road Operation

The first matter to be considered in this section is that of roadside friction, one of the principal reasons advanced for implementing access control such as by service roads. The very few case study comparisons indicated little difference in the occurrence of accidents at non-LSR versus LSR locations, and room for improvement through better design was found at both types of locations. A conflicts comparison at only one pair of sections indicated less potential hazard at the LSR location. The number of comparisons, however, were too few to permit conclusions as to safety to be made.

Comparisons of speed data for five pairs of sections with and without service roads indicated that speeds were essentially the same whether or not a service road was present. Increased speed on highways with service roads does not appear to be a concern. The amount of surrounding development seems to be a greater factor in this regard, a finding also reported by two other investigations. (58,63).

The conflicts comparison of various intersection types indicated no significant differences among either the three service road intersection types studied or the three highway intersection types studied. It is interesting to note, however, that on all Type D service road approaches (see Figure 2) not one conflict was observed, whereas on Type B service road approaches several conflicts were noted at many locations, especially where no control was in effect. These findings, considered together with the number of potential conflict points for the three-legged versus the four-legged intersection as illustrated in the introduction (see Figure 1), indicate that the best service road intersection type at crossroad locations is Type D.

At all such crossroad locations the width of outer separation is an important design element. It was especially apparent at the site with

the greatest separation (95 feet at site 23), that greater width promotes greater safety by providing better visibility of conflicting movements.

At highway intersections, most of the conflicts and many of the accidents involved vehicles exiting the highway at locations where no left or right turn lanes existed. The provision of a left or right turn lane as required is the obvious solution. Another difficulty experienced by four-legged highway intersections was accidents involving vehicles entering the highway as they entered or crossed the far-side direction of traffic. It appears that left-turning vehicles in the median often hide the approach of far-side highway traffic. Fewer median openings could reduce this hazard, but where required three-legged highway intersections with median channelization would be preferred.

In all cases where a crossover is provided, the width of the median should be sufficient to allow vehicles to enter or cross the highway one direction at a time. Such a median width would obviously enhance the safety of entering traffic as well as reduce delay, by allowing more efficient use of gaps in the highway traffic. In addition, the median should be wide enough to afford protection for vehicles sitting in the crossover. A recommended minimum is 30 feet as suggested by Stover (59).

As mentioned earlier in the data collection section, 24-hour volume counts were made on each section of service road studied, with the results presented in Table 16. From this information was developed a functional classification of service roads based on 24-hour volume and distinguished by type of land use. Such a delineation of service roads should provide valuable information for the planning stages of access development. Possible expected volumes as developed from actual volumes found in this study, and factors considered to affect them are shown in Table 17.

By visiting and observing several service road sites, certain relationships which are important to a driver of the service road and its connections to the highway became apparent. These relationships, which act to determine the operation of the service road at its intersections, are based upon two elements of the layout described as follows:

1. The direction of travel to be continued on the LSR relative to that on the highway, whether the driver continues in the same direction or whether he reverses his direction.

Table 16. Local Service Road Twenty-four Hour Volume Counts

Study Site and Land Use	Location of Counter	24-hour ADT	Monthly Factor	Approx. AADT
5050-5500 S. Madison Ave. (SR 431), Indianapolis Office - Commercial (June 24, 1974)	On LSR between access points of 5050 and 5140 S. Madison Ave.	403	.921	371
	On LSR between access points of 5140 and 5320 S. Madison Ave.	676	.921	623
	On LSR between access points of 5320 and 5410 S. Madison Ave.	527	.921	485
	On LSR between 5410 S. Madison Ave. and Epler Rd.(5500 S. Madison Ave.)	678	.921	624
5220-5350 W. Crawfordsville Rd. (US 136), Speedway Commercial (July 23, 1974)	On LSR between Gerrard St.(5220 W. Crawfordsville Rd.) and access point of 5236 W. Crawfordsville Rd.	481	.918	442
	On LSR between 5236 W. Crawfordsville Rd. and Lynhurst Dr.(5250 W. Crawfordsville Rd.)	595	.918	546
	On LSR between Lynhurst Dr. and 20th St. (5350 W. Crawfordsville Rd.), near Lynhurst Dr.	555	.918	510
	On LSR between Lynhurst Dr. and 20th St., near 20th St.	346	.918	318
707-1133 N. Coliseum Blvd. (US 30 Bypass), Fort Wayne Commercial (July 30, 1974)	On LSR between access points of 707 and 800 N. Coliseum Blvd.	227	.918	208
	On LSR between access points of 800 and 909 N. Coliseum Blvd.	638	.918	586
	On LSR between access points of 909 and 1001 N. Coliseum Blvd.	912	.918	837
	On LSR between 1001 N. Coliseum Blvd. and parking lot at 1133 N. Coliseum Blvd.	400	.918	367

Table 16. (cont.)

Study Site and Land Use	Location of Counter	24-hour ADT	Monthly Factor	Approx. AADT
1220-1520 S. US 31 Bypass, Kokomo Single family residential across highway from commercial (August 12, 1974)	On LSR(Imperial Dr.) at south approach to Savoy Dr.	523	.921	482
	On LSR(Imperial Dr.) at north approach to Saratoga Dr.	611	.921	563
	On Saratoga Dr. at south approach to LSR (Imperial Dr.)	2033	.921	1872
3000-3120 S. US 31 Bypass, Kokomo Single family residential (April 8, 1975)	LSR on west side (Reed Road) between Terrace Drive and Mayfair Drive	89	-	89
	LSR on east side (Garden Place) between Terrace Drive and Mayfair Drive	74	-	74
500-630 N. US 460, Clarksville Single family residential (August 20, 1974)	Low-angle diverge exit ramp from US 460 into LSR(Clark Blvd.)	1513	.921	1393
	Bowne Blvd. approach to LSR(Clark Blvd.)	2345	.921	2160
	On LSR(Clark Blvd.) between Bowne Blvd. and access point of 630 N. US 460	2679	.921	2467
	On LSR(Clark Blvd.) to west of 630 N. US 460	3122	.921	2875
1000-1200 E. Diamond Ave. (US 460), Evansville Industrial - Office - Commercial (September 10, 1974)	On LSR at west approach to New York St.	1666	.949	1581
	On LSR at east approach to New York St.	1145	.949	1087
	On New York Ave. at south approach to LSR	1777	.949	1686
	At the entrance, off a local street, to an LSR on the side of the highway opposite that studied	1054	.949	1000

Table 16. (cont.)

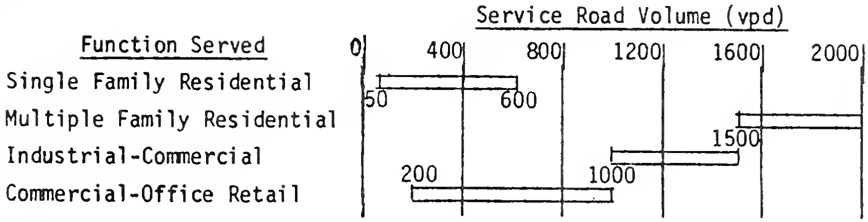
Study Site and Land Use	Location of Counter	24-hour ADT	Monthly Factor*	Approx. AADT
6500-6840 S. Madison Ave. (SR 431), Indianapolis Single family residential (September 17, 1974)	On LSR between Banta Road and Loretta Drive	127	.949	121
	On LSR between Loretta Drive and Maynard Drive	120	.949	114
	On LSR between Maynard Drive and Southview Dr.	161	.949	153
	On LSR between Southview Dr. and Tulip Drive	121	.949	115
8100 S. Madison Ave.(SR 431), Indianapolis Commercial and Multiple family residential (September 23, 1974)	On entrance driveway to shopping center and service road serving apartments	1515	.949	1438
	On exit driveway from shopping center and service road serving apartments	1066	.949	1012
	On apartment service road approach to shopping center driveway.	1862	.949	1767
6707-7107 W. Tenth Street, Indianapolis Single family residential (October 2, 1974)	On LSR between Bauman Road and Chapel Hill Rd.	255	1.005	256
	On LSR between Chapel Hill Road and western terminus with Tenth Street	117	1.005	118
	On Bauman Road at south approach to LSR	1795	1.005	1804
	On Chapel Hill Road at south approach to LSR	1856	1.005	1865

*1974 Suburban Monthly Factors (provided by the Indiana State Highway Commision)

May - 0.961	August - 0.921
June - 0.921	September - 0.949
July - 0.918	October - 1.005

November - 1.037

Table 17. Functional Classification of Service Roads



Bar graph showing possible expected 24-hour volumes for various types of land uses.

Factors which may affect the above values:

Single Family Residential: 50-600 vpd depending on size of subdivision, other access to it, and frequency of connections to highway

Multiple Family Residential: 1500-2000 vpd when serving an apartment complex, depending on number of apartments and other means of access

Industrial-Commercial: 1000-1500 vpd when serving several small industries

Commercial-Office Retail: 200-1000 vpd depending upon extent of development and frequency of access points to the highway

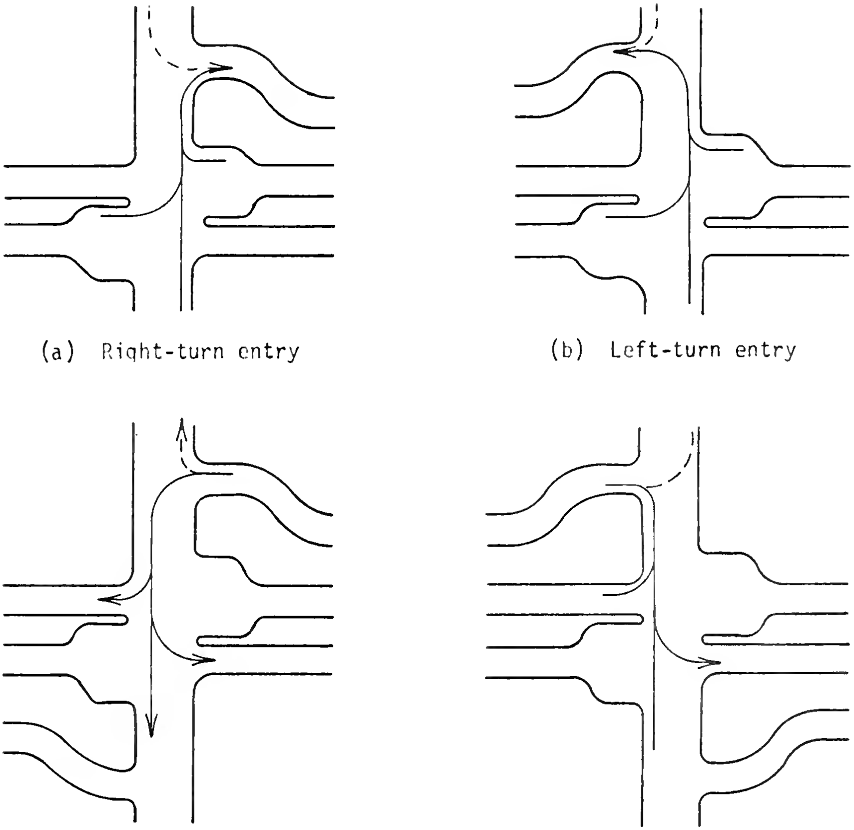
2. The service road treatment at the crossroad, whether for the driver the service road begins at the crossroad, terminates at the crossroad, or passes through the crossroad.

Together these characteristics act to define the pattern of turning movements regarding entry into and exit from the service road. Two of the patterns derived and their associated turning movements are shown in Figure 60. Observe that the left-turn entry is the more crucial of the two designs, due to possible left-turn queuing at the LSR entrance that could extend into the highway intersection. Note also that right-turn entry and left-turn exit actually occur at the same intersection, as do left-turn entry and right-turn exit. Further discussion of these two intersections will identify them by their entry movements only.

The better-operating right-turn service road intersections can be located in two of the diagonally opposite quadrants as shown. Similarly, the undesirable left-turn entry occupies the other two opposite quadrants. This undesirable left turn movement also exists where a service road passes through a crossroad, forming a four-legged LSR intersection. The complexity of movement at such intersections when located near a highway makes them most undesirable for design and operation, hence their use must be avoided.

An alternative means of access between the highway and the service road can be accomplished by the use of service road turnoffs. Again, operation is dependent upon the direction of travel to be continued relative to the highway, and whether the driver is entering or leaving the LSR. Figure 61 shows different patterns of movements at turnoffs, and possible desirable combinations of turnoff LSR's with crossroad-intersecting LSR's. One disadvantage associated with turnoff design is the additional median crossover often required, although its effect can be minimized by proper median design (channelization and width)and proper separation from the crossroad opening. The 500 foot minimum distance between median crossovers recommended by Stover (59) would seem appropriate.

Another disadvantage is the requirement that traffic on the crossroad wanting to reach the service road must travel on the highway. It is felt, however, that such highway travel would be preferred to queuing onto the highway associated with left-turn entry from the crossroad, thus



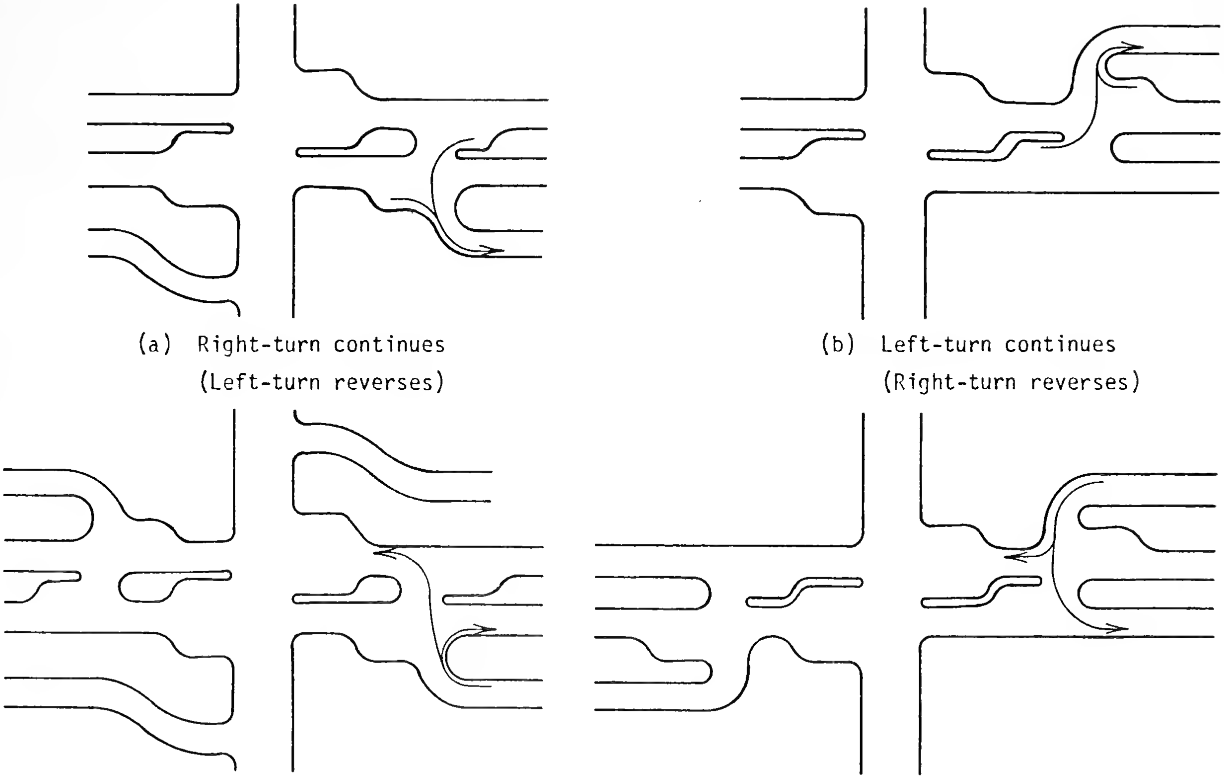
(a) Right-turn entry

(b) Left-turn entry

(c) Left-turn exit

(d) Right-turn exit

Figure 60. Turning Movements Between a Highway and Its LSR at a Crossroad



Entry into LSR

Exit from LSR

(a) Right-turn continues
(Left-turn reverses)

(b) Left-turn continues
(Right-turn reverses)

(c) Left-turn continues
(Right-turn reverses)

(d) Right-turn continues
(Left-turn reverses)

Figure 61. Turning Movements Between a Highway and Its LSR at Turnoffs

in such quadrants a turnoff is recommended.

Recommendations for Design

This section will draw upon the accident experience and the conflicts regression analysis to develop specific design recommendations for each type of intersection studied. Also considered will be those intersection configurations for which too few sites were found for the conflicts analysis. For illustration of all types of intersections to be mentioned, see Figures 2 and 3.

For Type A service road intersections, where access from the highway is provided to the service road, the conflicts regression equation gave heavy weighting to the volume sample on the service road as the variable which best explained the conflicts index. This result indicates that the 24-hour service road volume, which generally can be estimated for planning purposes,is the basis for a critical volume beyond which Type A access openingsshould not be developed. Although a considerable void existed between the last two volumes in Table 18, an expected AADT of about 2000 vehicles per day (vpd) would seem a reasonable maximum for such access openings.

Table 18. Listing of Volumes and Operational Experience for Type A Intersections

Identification No.	Location	Approximate AADT	Number of Accidents	Confs. Index
01	West Lafayette (US 52)	440	0	0.172
06	Speedway (US 136)	494	0	0.590
09	Fort Wayne (US 30)	208	0	0.509
11	Fort Wayne (US 30)	602	0	0.464
13W	Kokomo (US 31)	89	0	0.214
15	Kokomo (US 31)	1214	0	0.116
16	Clarksville (US 460)	2671	2(1-1/2 yrs.)	9.979

Where more than 2000 vpd are expected on the service road, any access connection should be achieved by some other means where the volume would not be critical, such as perhaps Type C turnoffs. The highway median at

a Type A access point is best carried through, based on the accident experience of the median at site 15 (Type G). Where a median opening is used at Type A access, it is best designed with no driveway or crossroad located opposite the service road access.

Where the median is carried through at such an access point, a Type G intersection is found on the highway. Regression analysis of conflicts at these intersections revealed the two most important variables, the values of which are presented in Table 19, as those involving entering and leaving right turns with respect to the highway. The regression equation developed was significant at the 0.10 level, and gave a correlation coefficient squared R^2 of 0.856. While no trends appear evident in Table 19, it stands to reason that with proper design (large radius curvature and/or deceleration and acceleration lanes, etc.) the effects of these right turns can be minimized.

Table 19. Listing of Important Variables and Operation Experience for Type G Intersections (Highway Approach)

Proj.No.	Location	TVNR	TPXR	Conflicts Index	No.Accs.
06	Indianapolis (SR 431)	24	0.430%	58.156	0
10	Speedway (US 136)	30	0.375%	39.265	0
13	Fort Wayne (US 30)	49	1.100%	0.000	1
15	Fort Wayne (US 30)	19	0.306%	0.000	0
21	Kokomo (US 31)	104	2.075%	0.00	2(1-1/2 yrs)
24	Evansville (US 460)	102	1.490%	317.432	2

Keeping in mind that the Type A openings are desirable only where less than 2000 vpd use the service road, an absolute minimum design for these access openings would be based on an outer separation of 40 feet. All such openings should be approached by at least a 10 foot wide right turn lane, leaving a 30 foot wide (radius=15 feet) separation, one foot under the AASHO minimum U-turn radius for a passenger vehicle. The exit side of the access may have a minimum radius of 16 feet (3), leaving 8 feet of separator width for taper back to the highway. The width of the opening itself should be at least 40 feet, and as much as 50 feet where a median opening exists. When greater than 50 feet is used, a divider

island no wider than 10 feet is suggested for proper channelization. A minimum design suggested for industrial-commercial areas is that found at site 16, as shown in Figure 62. In all cases, the near edge of any private driveway connecting to the service road should be no closer than 50 feet from the near edge of the intersection, so as to insure three-legged operation of the opening on the service road.

Regression analysis for the service road approach of Type B intersections, where a service road passes through a crossroad, indicated the three variables SVS, TVS, and VTI (see Table 4) as explaining the conflicts index with a correlation coefficient squared R^2 of 0.941. Upon forming Table 20 with these variables, abouc the only consistency that appears is that where the ratio of crossroad traffic to service road traffic (SVS) is considerably greater than one, the conflicts index and also the accident experience indicate a safer condition. Or, to say the same thing in a different way, where the amount of traffic on the service road is considerably less than that on the crossroad, operation is acceptable. Clearly, however, on low volume service roads low crossroad volumes of a similar size would not be detrimental. Thus what is indicated is a maximum acceptable service road volume for the installation of a four-legged service road intersection with a crossroad. Consideration of the approximate 24-hour volumes as added to Table 20 would suggest this maximum be no more than 400 vpd. This recommendation means that such four-way service road intersections are acceptable only for fairly short service roads in certain lower density single family residential areas and similar low density business areas.

It is imperative that all service road approaches to a crossroad be controlled by STOP signs, as determined from the accident analysis. In addition, the crossroad must be of such a nature that it will never be signalized at either the service road or the highway, as again indicated from the accident analysis for Type B service road intersections. Thus, streets designated as collector or higher, and moderate generator commercial driveways, should not have a service road passing through them.

The suggested minimum design for the Type B access opening must take into consideration the operational characteristics of the crossroad,

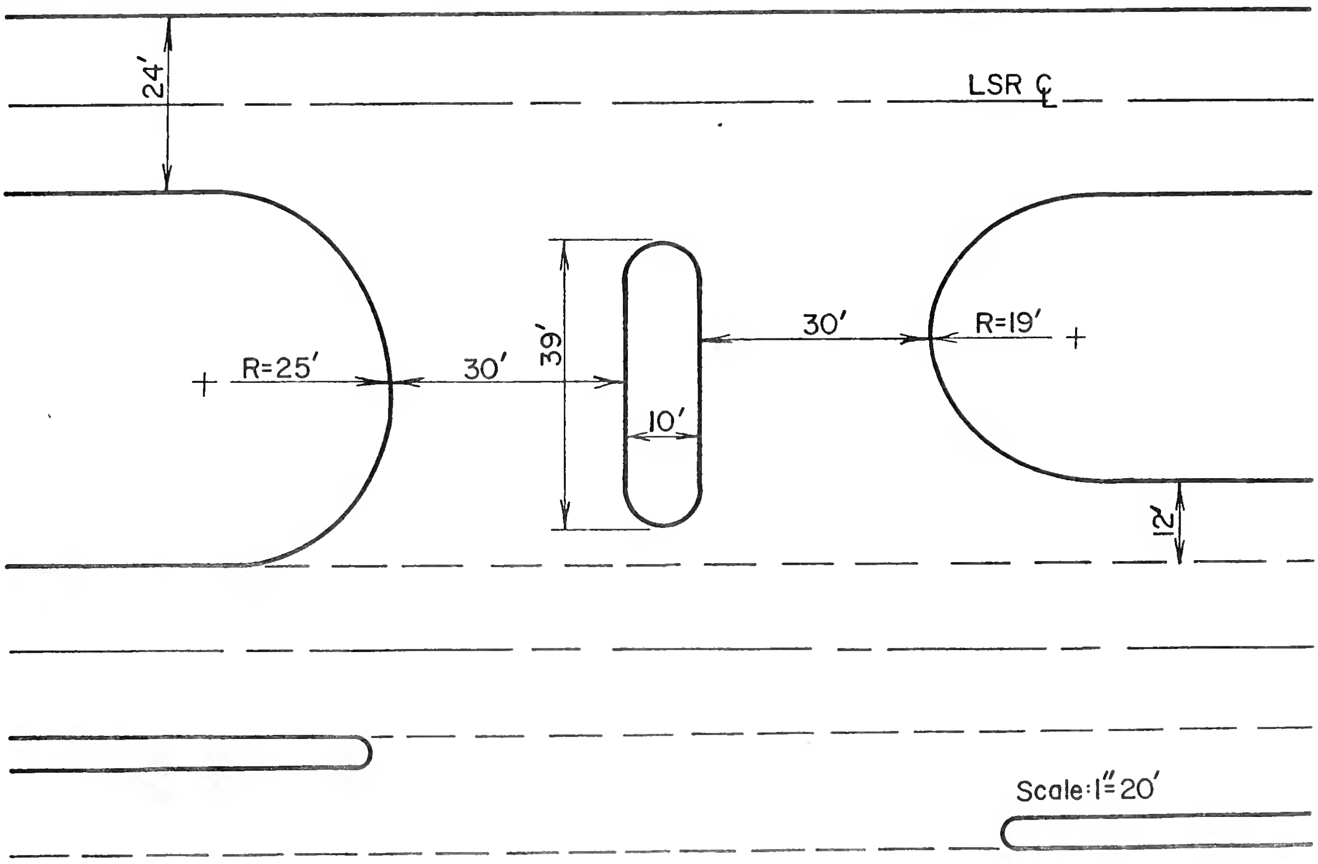


Figure 62. A Suggested Access Connection Design for Industrial-Commercial Areas

Table 20. Listing of Important Variables and Operational Experience for Type B Intersections (LSR Approaches)

Identification No.		SVS	TVX	VTI	Confs. Index	No. Accs.	Approx. AADT*
02	Indianapolis (SR 431)	1.892	48	269	2.657	2	497
03	Indianapolis (SR 431)	0.384	26	108	1.592	1	554
04	Indianapolis (SR 431)	0.306	13	158	4.079	0	554
08	Fort Wayne (US 30)	0.440	71	193	0.000	2	711
10	Fort Wayne (US 30)	1.072	50	143	0.000	0	397
12	Kokomo (US 31)	6.500	21	165	0.000	0	310
18	Evansville (US 460)	0.593	141	411	0.000	2	1334
20	Indianapolis (SR 431)	3.955	13	109	0.118	0	118
21	Indianapolis (SR 431)	3.824	13	82	0.000	1	134
24	Indianapolis (SR 431)	6.053	17	134	0.000	0	134
27	Indianapolis (W.10thSt.)	9.750	13	170	0.000	1	187

*Taken as the average of the adjusted twenty-four hour volumes for the sections on each side of the crossroad.

where the regression analysis of conflicts indicated the width of the outer separation (WOS) as the most important factor, followed by the width of the crossroad (WRD) and the percentage of vehicles exiting the crossroad via a right turn (TPXR); together these variables explained the crossroad conflicts with an R^2 of 0.943.

Although the data in Table 21 do not indicate correlation between accidents and/or conflicts and the three variables, a width of separation of 40 feet is again suggested, or perhaps 50 feet, such as in Figure 63 in a low density residential and business area. Again, a right turn lane should exist on the highway at all such locations, and the minimum acceptable width of opening should be 50 feet, to allow for left turn storage onto both the service road and the highway. A median opening generally will be provided for this type of intersection, especially where the crossroad is a designated street. However, where a series of local streets or similar volume commercial driveways is perpendicular to the highway, it is much preferred that the service road collect and distribute local traffic with connections to the major facility by way of Type A access openings.

Regression at Type E highway intersections, where a parallel service road passes through the crossroad, indicated the volume of traffic exiting from the highway (TVX) as the first variable, with the median width (WMD) and total volume entering the intersection (VTI) giving an R^2 of 0.842. The only trend apparent in Table 22 involves generally a lower conflict rate where the median is wider, but the accident experience indicates differently due to the higher volumes at the wider median sites. A minimum median width of 30 feet is suggested to allow traffic to cross one direction at a time (59).

There were too few Type C intersections, where a service road makes a turnoff at the highway, to perform any conflicts analysis, but a consideration of the accidents at locations operating as a turnoff indicated the hazard of allowing a low angle of divergence from the highway into a two-way service road. This hazard was especially evident at site 05 where one vehicle went out of control as it entered. It appears that the nearer such a turnoff is to a right angle intersection, the greater slowdown of entry speeds will be accomplished, and the lesser encroachment on

Table 21. Listing of Important Variables and Operational Experience for Type B Intersections (Crossroad Approaches)

Proj. No.	Location	WOS	WRD	TPXR	Confs. Index	No. Accs.	Approx. AADT
02	Indianapolis (SR 431)	20	44	15.56	1.217	2	941
03	Indianapolis (SR 431)	20	30	16.67	0.169	1	213
04	Indianapolis (SR 431)	20	30	10.81	0.244	0	169
08	Fort Wayne (US 30)	30	24	18.64	0.630	2	313
10	Fort Wayne (US 30)	30	40	87.84	0.679	0	426
12	Kokomo (US 31)	62	34	17.01	4.937	0	1968
18	Evansville (US 460)	30	36	22.88	1.797	2	1686
20	Indianapolis (SR 431)	20	40	6.90	1.642	0	529
21	Indianapolis (SR 431)	20	40	6.15	1.327	1	513
24	Indianapolis (SR 431)	20	40	0.87	2.500	0	810
27	Indianapolis(W.10th St)	30	46	3.25	2.962	1	1865

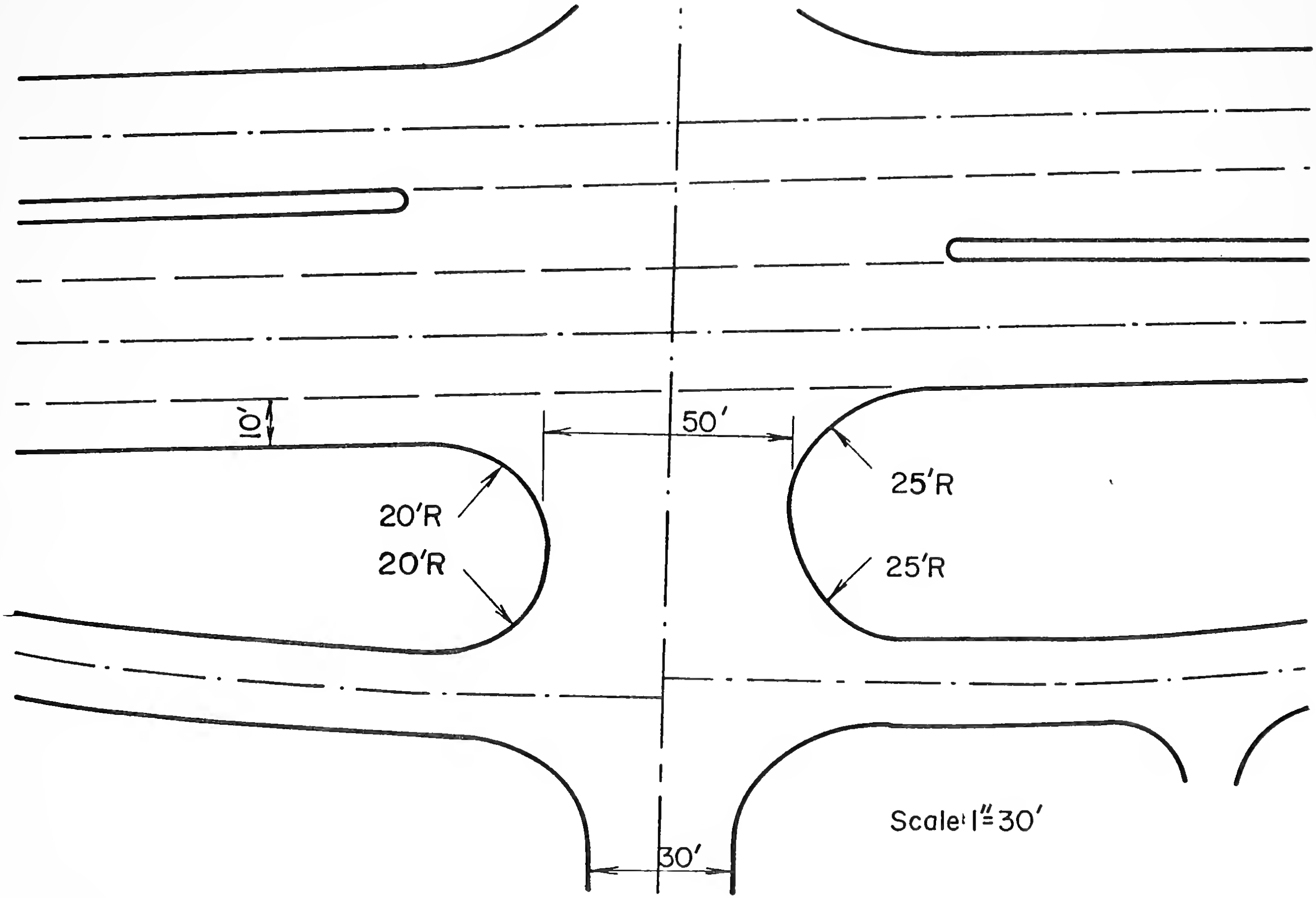


Figure 63. An Acceptable Design for a Low-Volume Four-Legged LSR Intersection Adjacent to a Highway

Table 22. Listing of Important Variables and Operational Experience for Type E Intersections (Highway Approaches)

Identification No.	Location	TVX	WMD	VTI	Conflicts Index	No. Accs.
02	Indianapolis (SR 431)	77	14	3645	127.509	4
04	Indianapolis (SR 431)	28	14	3611	432.364	11
10	Fort Wayne (US 30)	86	30	5565	6.228	4
11	Fort Wayne (US 30)	109	30	5536	20.612	13
12	Kokomo (US 31)	74	36	4516	4.011	41
16	Clarksville (US 460)	99	14	4435	111.326	5
20	Indianapolis (SR 431)	45	14	3076	187.552	1
21	Indianapolis (SR 431)	33	14	3138	212.772	2
24	Indianapolis (SR 431)	50	14	3241	179.310	2

the opposing lane will occur.

In developing design recommendations for turnoffs, it should first be noted that turnoffs can be laid out in two ways. These can best be differentiated by considering the right turn exit from the highway, where in one case a U-turn is made; in the other an S-turn movement is made. For the U-Turn turnoff, the centerline should intersect with the highway at no less than a 90° angle. A minimum 10 foot wide turning lane should be provided, and a suggested minimum radius for the 180° turn is 15 feet.

For the S-turn entry, a design such as shown in Figure 64, where the angle of intersection is about 70°, the radius is 25 feet, and the throat width is 30 feet, would seem a good design. Again, a right turn lane must be provided at such entrances to encourage the deceleration necessary to safely negotiate the reverse curve. Such service road terminal points often will need to allow vehicles the flexibility of coming and going from any direction, for which a median crossover would be appropriate. An opening opposite the turnoff might also be required. No difficulty should be experienced in handling the upper range of service road volumes at such access points, but such intersections might eventually require signalization, a condition found to be desired by merchants.

The Type D intersections, where the service road terminates at a crossroad, experienced conflicts only on the crossroad, which were found to be explained by the crossroad volume sample (HVS), the width of the service road (WDR), and the volume turning onto the service road via a right turn (TVXR). It should be noted that previous analysis of Type D intersections has made no distinction between left-turn entry and right-turn entry service road configurations, where five of the former and four of the latter were available. The only trend apparent in Table 23 is that where the crossroad volumes are higher, so are the conflicts indices.

Looking now at the right turn service roads, clearly no problem exists at the low volume single-family residential locations of sites 14E and 22, where the separation is 50 and 20 feet respectively. However, sites 23 and 26 seem more valuable in establishing design conditions. At site 26, in a single family residential area, the separation is 30 feet as is the crossroad width, whereas for the somewhat higher volume site 23, in a commercial-apartment area, the separation is 95 feet and the crossroad

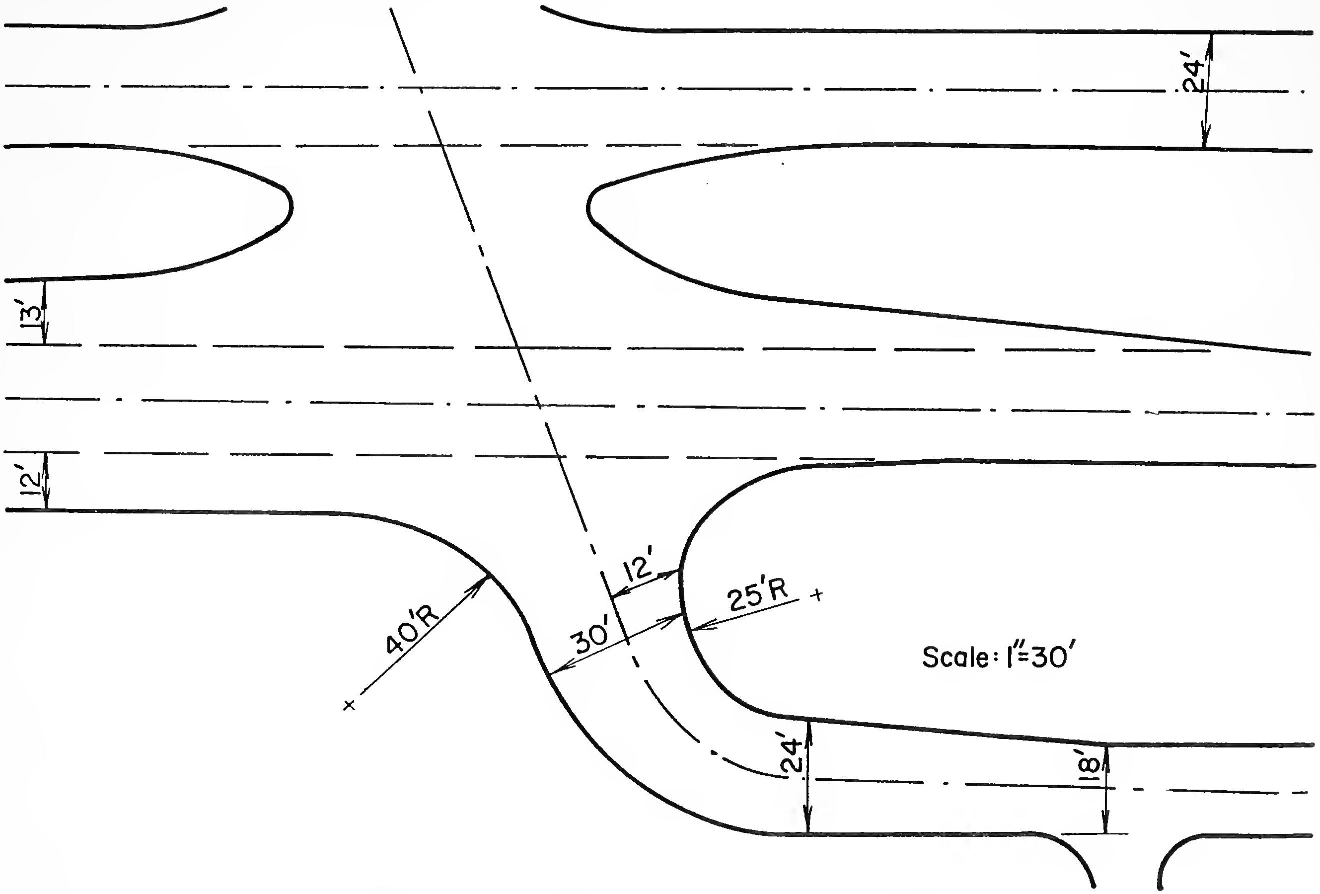


Figure 64. A Suggested Design for an LSR Turnoff

Table 23. Listing of Important Variables and Operational Experience for Type D Intersections (Crossroad Approaches)

Identification No.		HVS	WDR	TVXR	Confs Index	No. Accs	Approx. AADT*
07	Speedway (US 136)	84	22	11	1.292	0	583
13E	Kokomo (US 31)	22	24	4	0.000	0	148
14E	Kokomo (US 31)	197	24	9	0.000	0	729
14W	Kokomo (US 31)	153	18	1	14.308	0	685
19	Evansville (US 460)	568	30	23	21.055	2	3690
22	Indianapolis (SR 431)	40	24	4	0.000	0	242
23	Indianapolis (SR 431)	384	30	64	6.905	1	2450
25	Indianapolis (SR 431)	429	24	1	42.421	0	4290
26	Indianapolis (W.10th St.)	219	22	11	5.390	0	2000

*Derived by applying 24-hour expansion factor of service road volumes to crossroad sample.

Underlined locations indicate left turn entry from the highway access.

is designed with a divider as in Figure 65. Note that site 26 performs only slightly better than site 23 in spite of the much greater right turn volume at the latter, thus the 2000 AADT volume at site 26 might be a maximum crossroad volume for a separation of as low as our minimum of 40 feet.

Where the crossroad volume would be expected to exceed 2000 vehicles in a 24-hour period, more than 40 feet of separation should be provided, as should additional crossroad width. The greater separation with the greater crossroad volume affords those vehicles exiting left from the service road a better opportunity to enter the crossroad, and two lanes in each direction on the crossroad will reduce delay by separating the through and turning movements at both the highway and service road intersections.

A median divider on the crossroad provides positive separation of opposing traffic and helps define the limits of turning movements. If the crossroad might ever become signalized, a separation of at least 150 feet would probably be necessary, depending upon left-turn storage lane requirements at the highway. Such separation would also allow provision of a right turn lane into the service road. The reverse curve treatment of Figure 65 is an effective guideline for widening of the outer separation at the crossroad, adhering to the AASHO recommendation that "the radius of the flatter circular arc (R_1) should not be more than 50 percent greater than the radius of the sharper circular arc (R_2)". (2).

Although a t-test indicated no significant difference of the means of the conflicts index for the left-turn versus the right-turn service roads, at the higher crossroad volumes the left-turn service roads appear to present problems, even at low service road volumes such as site 25. Thus such a design with a separation of as little as 40 feet would appear to be acceptable only where the expected crossroad 24-hour volume is less than about 500 vpd. Where the crossroad would have a greater AADT, the design should locate the service road intersection at least 150 feet away from the highway, a distance considered acceptable by AASHO. Where the crossroad might become signalized, the sum of the left-turn storage requirements for both the highway and the service road governs the separation. Again, the reverse curve treatment should consider the difference in radius; a design using the same radii as in Figure 65 would be satis-

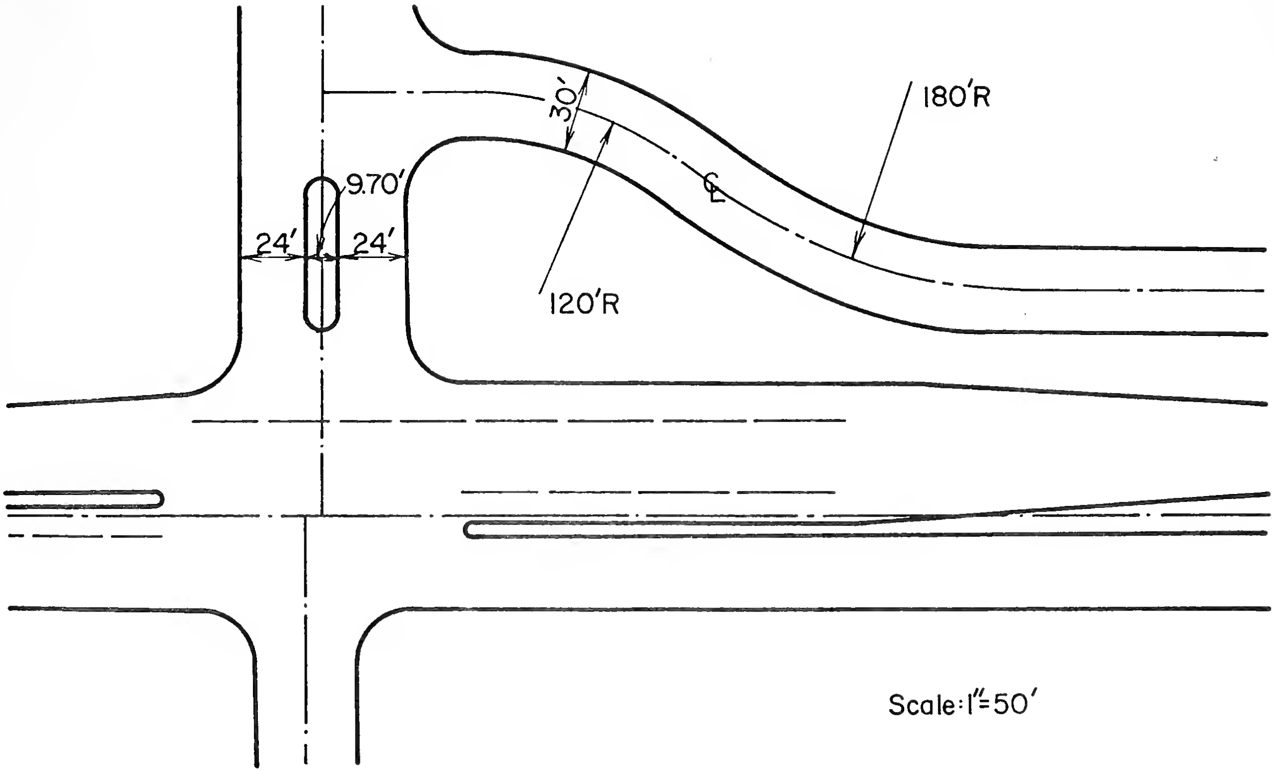


Figure 65. A Desirable Design for Widening the Outer Separation at an LSR Terminus

factory, the only difference being that the deflection angle would be greater for the greater separation. Where right-of-way or other considerations would make such a left-turn entry service road prohibitive, a Type C turnoff from the highway about 500 feet beyond the crossroad is a suggested alternative.

It would be considered acceptable, where the expected crossroad volume does not exceed 2000 vpd and where no signal would be installed on the highway, to allow two adjacent service road intersections, one with right-turn entry separated from the highway by at least 40 feet, the other with left-turn entry separated from the highway by at least 150 feet. The crossroad in this instance must be four lanes wide, to allow through vehicles to pass those vehicles turning left into the two service roads. A narrow but visible divider would be desirable to separate these opposing turning movements, and also any other driveway must not be permitted in the intervening distance of 110 feet. Also, a minimum of 50 feet should separate the left-turn service road and any adjacent or across-the-road access on the crossroad.

Conflicts on the highway at crossroads where a service road terminates (Type H intersections) were explained best by the combinations of variables WMD and TVN, yielding an equation with an R^2 of .960. Analysis of Table 24 does not yield any conclusive design trends, thus the only recommendations for this type of intersection are based upon individual intersection experience.

The comparatively higher accident occurrence at site 23, as discussed in the accident analysis, probably reflects the greater use of this intersection. The conflicts problem at sites 05 and 22 results from not having a right turn lane, which along with left turn lanes are recommended for installation at all crossroad intersections.

Factors to be considered regarding the spacing of any type of access connection between the highway and its LSR include:

1. The spacing of median crossovers, which in Indiana is a minimum of 400 feet and is recommended as a minimum of 500 feet by recent research (59).
2. Acceleration and absorption into the traffic stream. Major and Buckley (36) found that the distance to assimilate vehicles en-

Table 24. Listing of Important Variables and Operational Experience for Type H Intersections (Highway Approaches)

Identification No.		WMD	TVN	Conflicts Index	No. Accs.
05	Indianapolis (SR 431)	14	12	444.931	2
13E	<u>Kokomo</u> (US 31)	40	9	102.083	1
14E	Kokomo (US 31)	40	74	3.346	0
14W	<u>Kokomo</u> (US 31)	40	35	19.832	0
22	Indianapolis (SR 431)	14	22	342.576	1
23	Indianapolis (SR 431)	14	153	17.595	5

___ Left-turn entry into LSR from the highway.

tering one lane of traffic is about 1.5 times the distance of acceleration to the mean speed of the highway traffic. Perhaps where the highway traffic is in two lanes this distance might reduce to about 0.75-1.00 times the acceleration distance. This criterion would suggest access spacing of 600-800 feet for entry into 40 mph traffic, and 1100-1400 feet for entry into 50 mph traffic, using AASHO passenger vehicle acceleration curves (2).

3. Frequent enough to prevent an unreasonable distance of circuitous travel, and to avoid backup delay at exits due to probable higher volume from greater spacing.
4. Consideration of existing or projected spacing of local streets.
5. Provision of adequate sight distance at all access locations. A service road can provide access to locations where sight distances would prohibit such by connecting with points of safe access (31).

A final suggestion concerns the address designation of establishments and residences located on service roads. Inconsistencies in the naming of the service road were found to exist; for instance at one location along SR 431 (Madison Ave.) in Indianapolis, the service road was called Madison Way, at another location it was Madison Drive. At another site in Indianapolis the service road was called 38th St. North Drive. Rather than these inconsistent designations, the author recommends the use of the term "Frontage" to indicate such locations, as for example, Madison Frontage, or 38th Frontage. Thus if someone unfamiliar with the area would look for 5320 W. 38th Fr., he would understand that the location is on a service road, and should thus seek the address from a facility serving local traffic. Establishments with access directly to the highway should be addressed as is currently done, for instance 5050 W. 38th St. It is hoped that such a distinction,once it would become conventional, could assist drivers in locating service road establishments, thereby facilitating the separation of through and local traffic.

Application to State Road 26

The results and findings of this research are useful in developing design alternatives for locations where service road access control is proposed. One such highway is a two-mile stretch of Indiana State Road

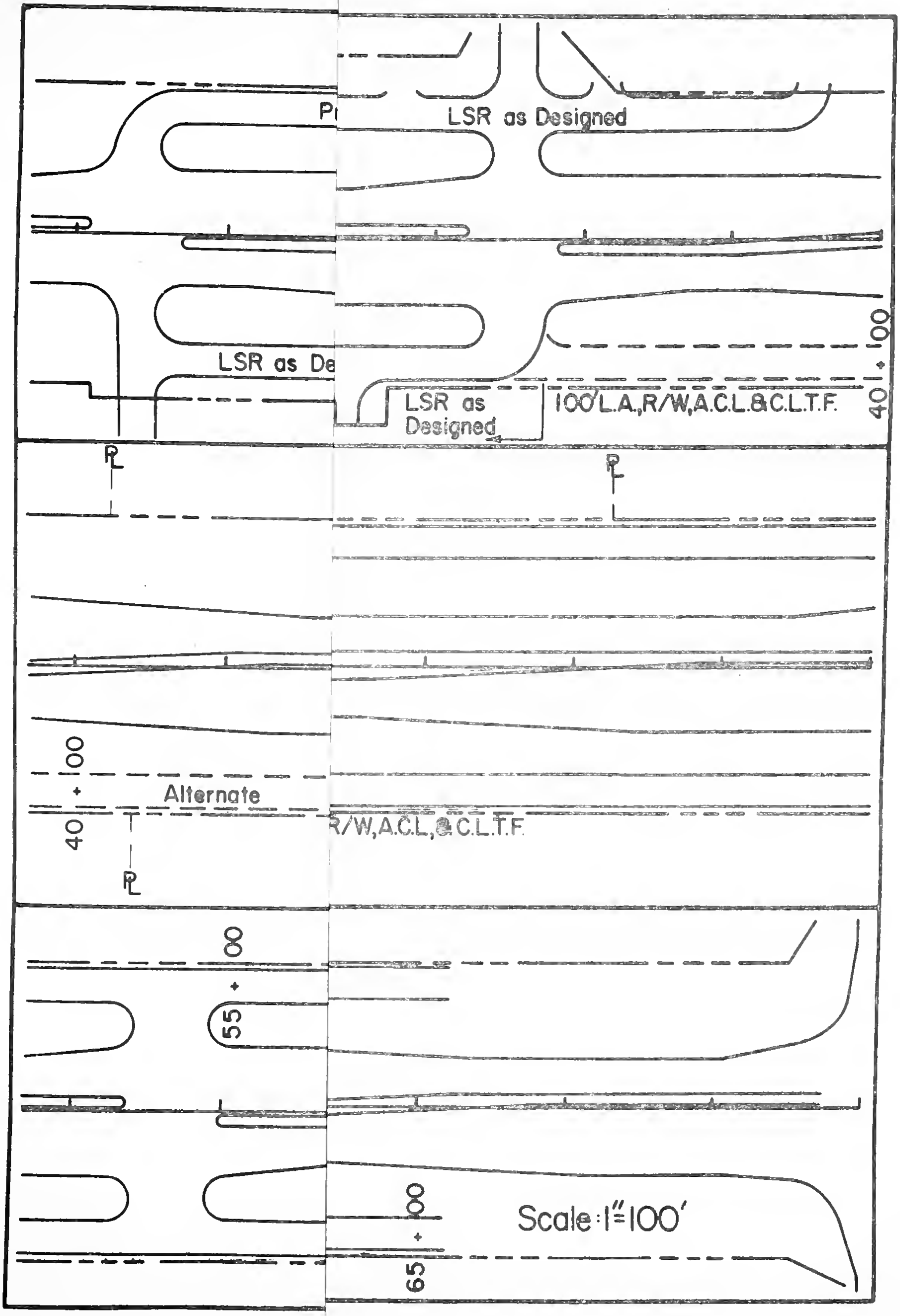
26, extending east from Lafayette between the US 52 Bypass and Interstate 65 where an interchange is located. As of 1975 the one-half mile nearest the bypass is fairly well-developed, consisting of mostly light industry and warehouses. A drive-in theatre and two street intersections are also present in this half-mile portion. The rest of the highway is surrounded by undeveloped farmland, with the exception of an auto dealership on one corner of the major crossroad at the midway point; and some houses, motels and apartments near the Interstate interchange. In the next several years this stretch of highway and the surrounding land is expected to undergo considerable development, especially upon completion of the State's current plans to upgrade the highway to a divided four-lane facility with partial access control.

The plans for upgrading have already provided some local service roads for existing development along the highway. These access roads, along with other authorized driveway locations and median openings, formed the starting point for the creation of a service road access plan for this entire site. This plan, as shown in the three pages of Figure 66, provides for practically any form and pattern of development that might occur by suggesting alternative configurations such as that between stations 37+50 and 43+00. In a similar manner possible alternative treatments at the major crossroad are presented, as shown on sheet 2 of Figure 66. The left-turn entry into the service road at stations 31+00 and 101+50, while not desirable, is the only design alternative available due to existing development.

The use of turnoffs beyond the crossroad intersection is suggested where a major development, having access by way of the crossroad, would be constructed on a corner. Such major developments could also be designed with connections to the service road.

The suggested design has made considerable use of the Type A service road access opening, which appears to operate satisfactorily up to a service road volume of about 2000 vpd. As this is a relatively high volume for a service road, this type of access should accommodate just about any type of ribbon development that might occur. No driveways should be located at or near such service road access openings for at least 50 feet from the edge of the access point. The traffic control suggested for such

Figure 66. A Plan for the Provision of Local Service Roads Along State Road 26 at Lafayette, Indiana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LSR as Designed
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LSR as Designed
100 L.A.,R/W,A.C.L.&C.L.T.F.
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40 + 00
55 + 00
65 + 00
Scale: 1" = 100'

Figure

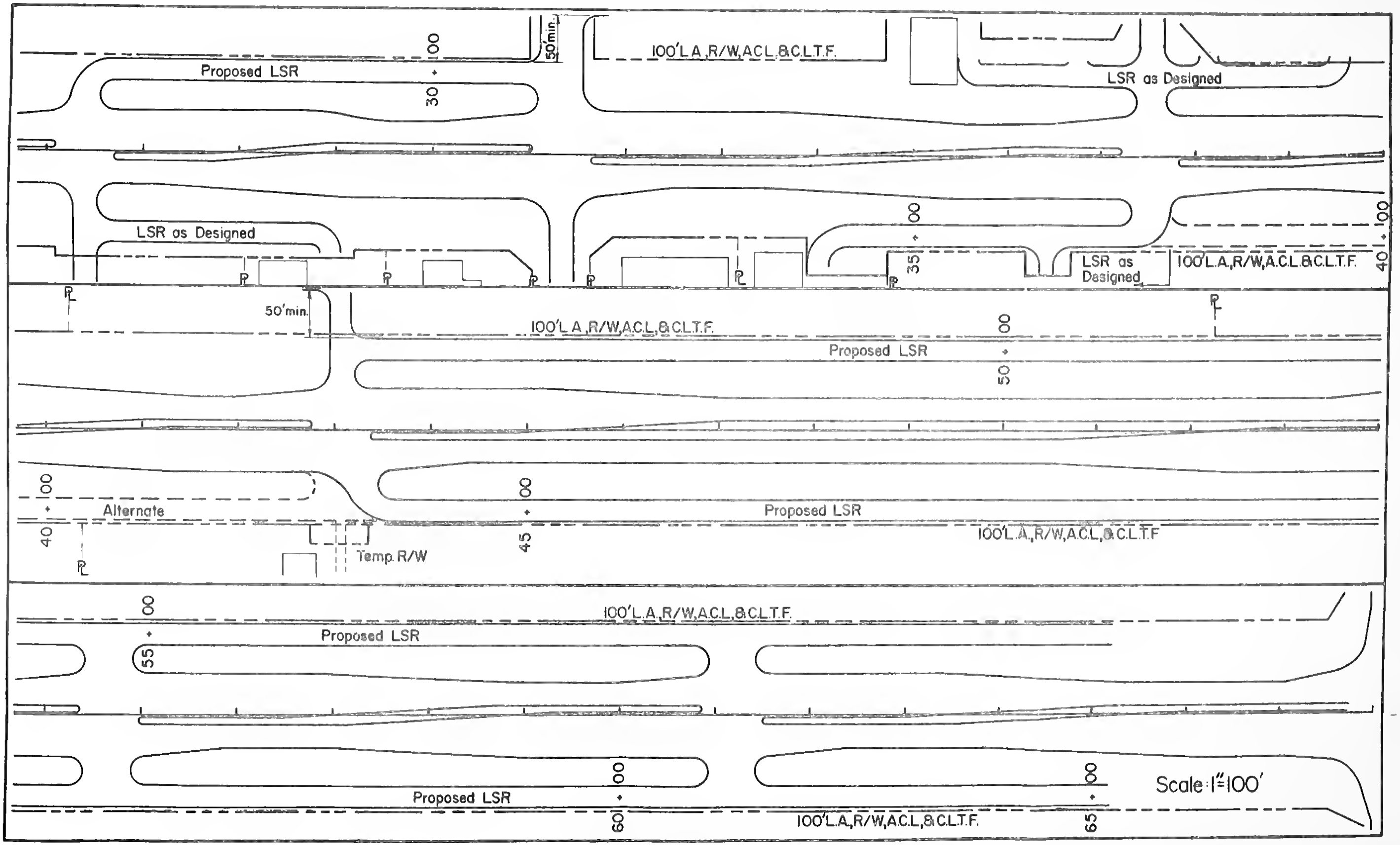
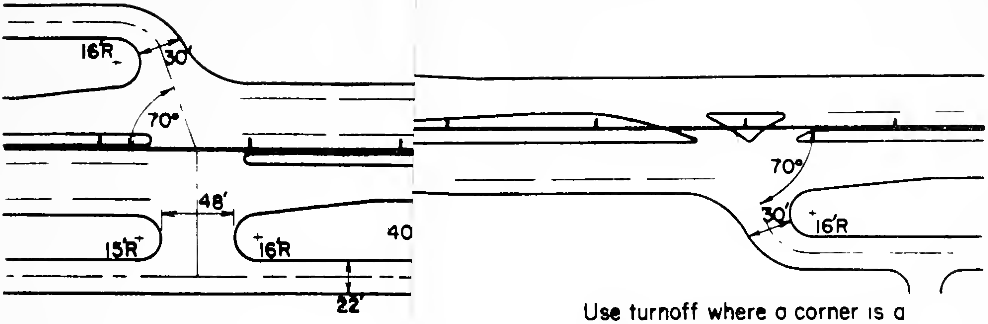
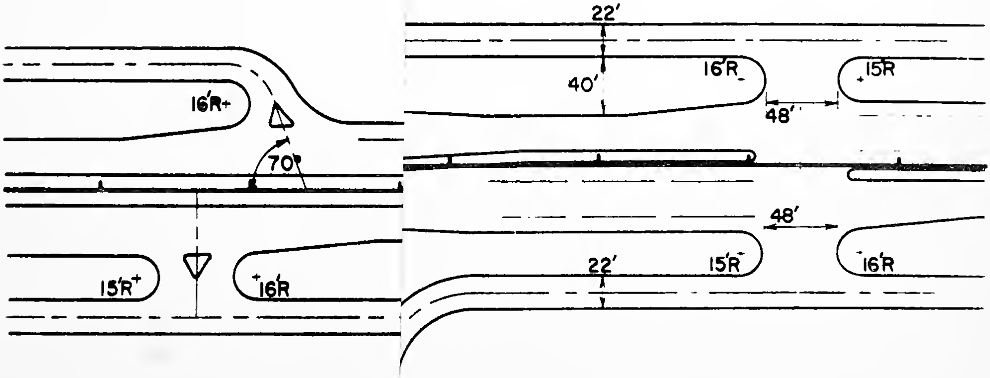


Figure 66., cont.



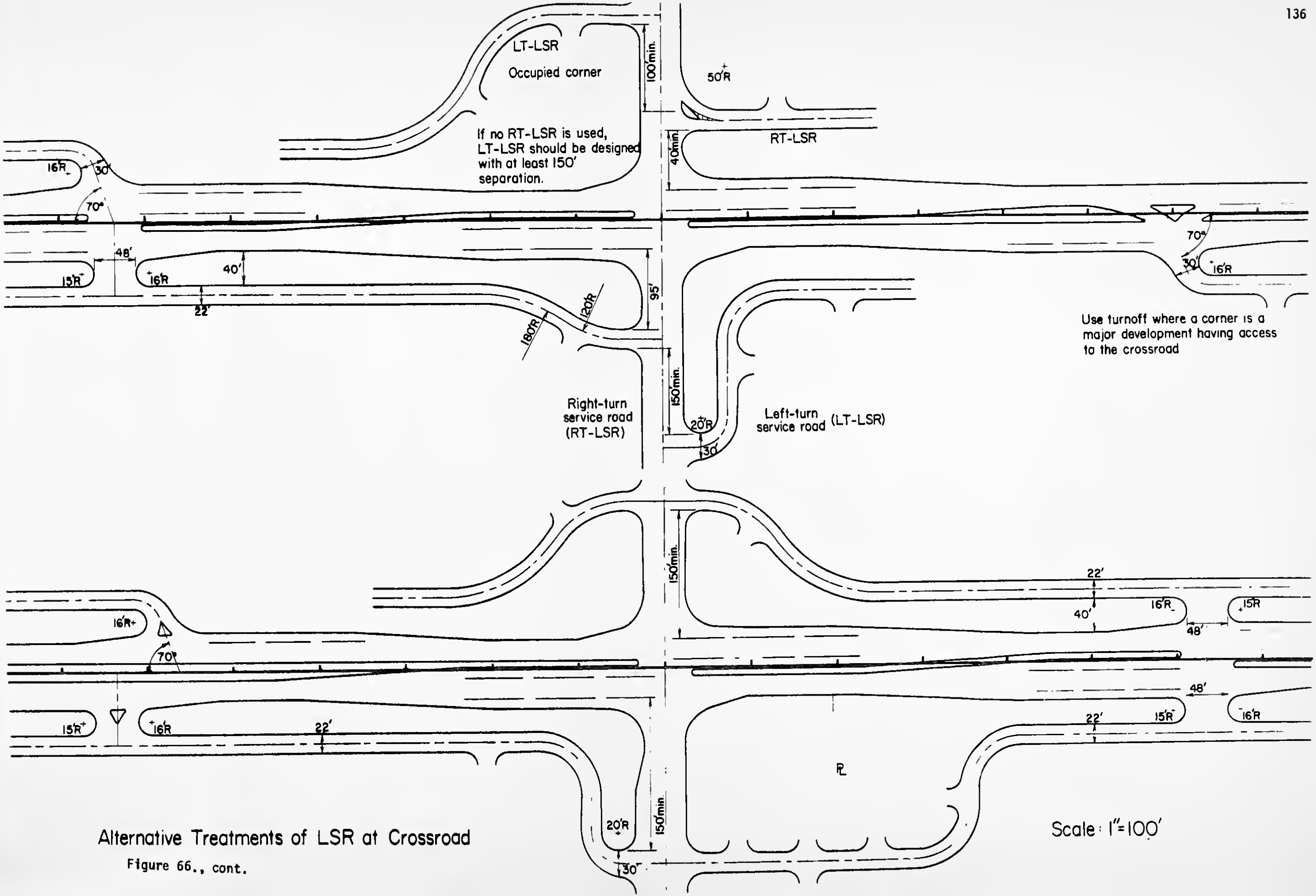
Use turnoff where a corner is a major development having access to the crossroad



Scale: 1" = 100'

Alternative Treat

Figure 66., con



Alternative Treatments of LSR at Crossroad

Figure 66., cont.

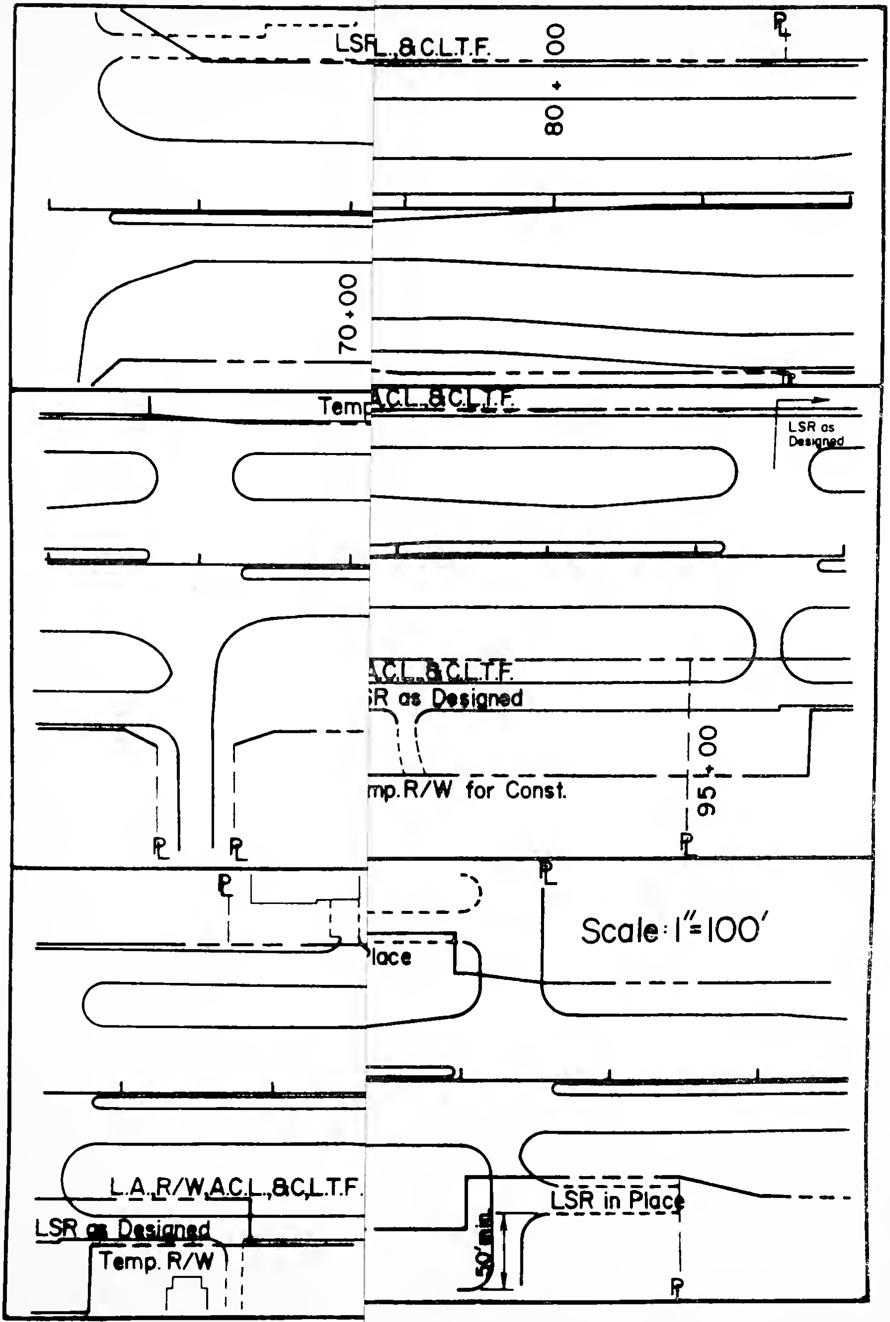

LSR L., & C.L.T.F.
80+00
70+00
Temp A.C.L. & C.L.T.F.
LSR as Designed
A.C.L. & C.L.T.F.
SR as Designed
mp. R/W for Const.
95+00
Place
Scale: 1"=100'
L.A. R/W, A.C.L., & C.L.T.F.
LSR as Designed
Temp. R/W
LSR in Place
50' min.

Figure 6

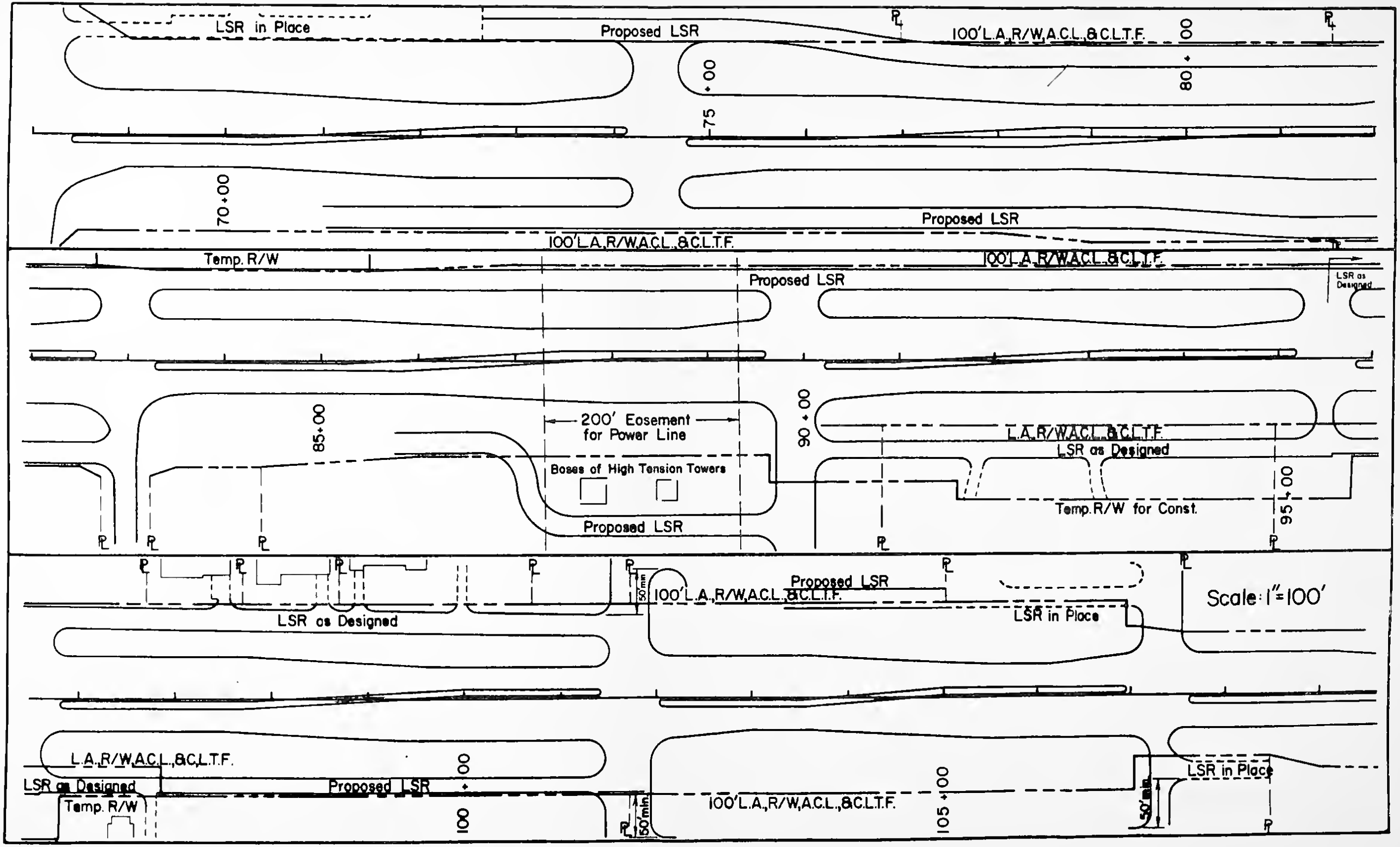


Figure 66., cont.

openings is the STOP sign on both service road approaches to the opening. This control is suggested for two reasons:

1. Because of the restricted view to drivers on the service road approaches
2. To expedite the movement of vehicles off the highway onto the service road so as not to have queuing onto the highway.

Note the use of right- and left-turn highway lanes at turnoffs and service road access points. For a 45 mph design speed AASHO recommends about 375 feet of deceleration length for slowing to a stop condition. This distance is suggested for right-turn lanes wherever a U-turn onto the service road exists, a maneuver which can be made only at low speeds. For a right-turn turnoff in which the driver continues in the same direction on the service road as he did on the highway, this deceleration length may be reduced by about 50 feet.

CONCLUSIONS

Conflicts data, speed data, accident data, and questionnaire data lead to the following conclusions:

1. The comparison of the conflicts index for the various types of service road intersections and highway intersections was considered unreliable due to the substantial variation of design and volume among the study sites within each type. It is considered important however, that no conflicts were observed on the service road approaches of three-legged LSR-crossroad intersections. The small number of LSR versus non-LSR case study comparisons and their peculiarities in design did not permit any conclusions to be made from their data.
2. The speed characteristics of vehicles on the highway in commercial, residential, and industrial LSR areas were not found to differ significantly from the speed characteristics in such areas where direct access was permitted.
3. A major cause of accidents at highway intersections with adjacent service road intersections was the omission of right-and left-turning lanes and inadequate median width for storage and U-turns.
4. It appears that commercial establishments on service roads fared just as well, if not better than, those with direct access to the highway, who themselves felt that some benefit can accrue from service road access control.
5. The variable found to best explain conflicts on the service road approaches to Type A intersections was, with a high degree of reliability, the volume on the service road.
6. The combination of variables found to best explain conflicts on the service road approaches of Type B four-legged intersections was, in order of importance,
   a. The ratio of crossroad traffic to service road traffic

b. The volume of traffic exiting from the service road
c. The total volume of traffic entering the intersection.

7. The combination of variables found to best explain conflicts on the crossroad approaches of Type B four-legged intersections with service roads was, in order of importance,
   a. The width of the separation at the crossroad
   b. The width of the crossroad
   c. The percentage of vehicles exiting the crossroad via a right turn.
8. The combination of variables found to best explain conflicts on the crossroad approaches of Type D three-legged intersections with service roads was, in order of importance,
   a. The volume of traffic on the crossroad
   b. The width of the service road
   c. The volume of traffic exiting the crossroad via a right turn.
9. On the basis of this data, the following recommendations for design and operation were developed:
   a. Type A access connections between the highway and the service road are desirable only where less than about 2000 vpd are expected to use the service road.
   b. Type B four-legged LSR intersections are not desirable within 150 feet of the highway, but where required to as near as 40 feet of the highway, the expected service road volume should not exceed about 400 vpd.
   c. For Type D three-legged LSR intersections at a crossroad, a distinction between intersections involving right-turn entry and left-turn entry into the LSR appeared appropriate. For right-turn intersections a maximum expected crossroad volume of about 2000 vpd would be acceptable for a separation from the highway of as little as 40 feet. For left-turn intersections this maximum crossroad volume would be about 500 vpd, otherwise the design should locate the left-turn intersection at least 150 feet away from the highway.

RECOMMENDATIONS FOR FURTHER RESEARCH

Through the course of this research study, other additional areas were identified that require further study to achieve a high quality of traffic service where service road and other forms of partial access control are applied.

1. Only two-way service roads were evaluated in this study, but as indicated in the literature review, one-way operation has several advantages worth investigating. A direct comparison of two-way versus one-way operation would be useful. One approach to such a study might be computer simulation of the various situations possible within each type of operation.
2. As turning lanes appear to considerably influence the operation of divided arterials, warrants for their installation should be refined. While some investigations were located dealing with warrants for left turn installation, none could be found regarding right turn lanes. Another aspect of divided lane highways which should receive early attention is the matter of accidents at median openings involving entering or crossing traffic and the far direction traffic on the highway.
3. In the event of implementation of the recommended design to SR 26 at Lafayette, an opportunity would exist to evaluate and perhaps refine the findings presented here. That opportunity should be accepted.

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APPENDIX A
Data Collection Sheets

Sample Form

FIELD INVENTORY SHEET

1. Location: City -
   Street -
   from - to -
2. Length of Section(ft)
3. Speed Limit(mph)
4. Width of Arterial(ft) No. of Lanes Parking?
5. Median Present? Width(ft)
   No. of openings No. with Lt-turn lane
6. No. of Intersections: 1 2 3 4 5 6 7 8 9 10 11 12
   Three-way? -
   Four-way? -
   Rt-turn lane? -
   Lt-turn lane? -
   Signalized? -
   Divided entrance? -
   Width(ft) -
7. Local Service Road
   On both sides of arterial? LT side RT side
   Length(ft)
   Width(ft)
   One way?
   No. of entrance points LT___ RT___ LT___ RT___
   Width of drive(ft), in succession:
      LT
      RT
   Type of Land Use served, in succession
   Type of terminal connections
      a) Crossroad T
      b) Arterial T
   Width of outer separation(ft) At crossroad
   Distance from edge of arterial to beginning of radius return(ft)
   Distance between openings(ft)
      LT
      RT

Figure A1. Field Inventory Sheet

Sample Form

CONFLICTS COUNT*

Intersection Name: Recorded by:

Count Start Time (Military)		
Weave	No. Vehs.	
	No. Confs.	
Left-turn from Wrong Lane	No. Vehs.	
	No. Confs.	
Right-turn from Wrong Lane	No. Vehs.	
	No. Confs.	
Turn into Wrong Lane	No. Vehs.	
	No. Confs.	
Opposing left-turn	No. Vehs.	
	No. Confs.	
Thru X-traffic Left to right	No. Vehs.	
	No. Confs.	
Thru X-traffic Right to left	No. Vehs.	
	No. Confs.	
Lt-turn X-traffic from left	No. Vehs.	
	No. Confs.	
Lt-turn X-traffic from right	No. Vehs.	
	No. Confs.	
Rt-turn X-traffic (from right)	No. Vehs.	
	No. Confs.	

Project No.: Intersection Approach No.:

*Continued on next page.

Figure A2. Conflicts Count

CONFLICTS COUNT (cont.)

Count Start Time (Military)		
Rear-end Conflicts	Stop on amber	
	Slow for left-turn	
	Slow for right-turn	
	Previous traffic conflict	
	Shopping entr. beyond intsn.	
	Slow truck	
	Congestion in intersection	
	Clear intersection	
	Stalled vehicle	
	Traffic back-up	
	Pedestrian	
	Merging beyond intersection	
	Single veh.-ped. conflicts	
	Weave-ped. conflicts	

<u>Sample Form</u>

VOLUME COUNTS

Intersection Name: Recorded by:

Count Start Time (Military)			
Sample Lane Only	Stopped	No brake lights	
		Brake lights operating	
		Rear of veh. not observed	
		Then turned	
	Slow		
	Thru undisturbed		
Left-turn	On green & amber		
	On red (violation)		
	On arrow (or red when legal)		
Thru - Green & Amber	Left lane		
	Left center lane		
	Center lane		
	Right center lane		
	Right lane		
Thru red (violation)			
Right-turn	On green & amber		
	On red (violation)		
	On arrow (or red when legal)		

Project No.: Intersection Approach No.:

Figure A3. Volume Count

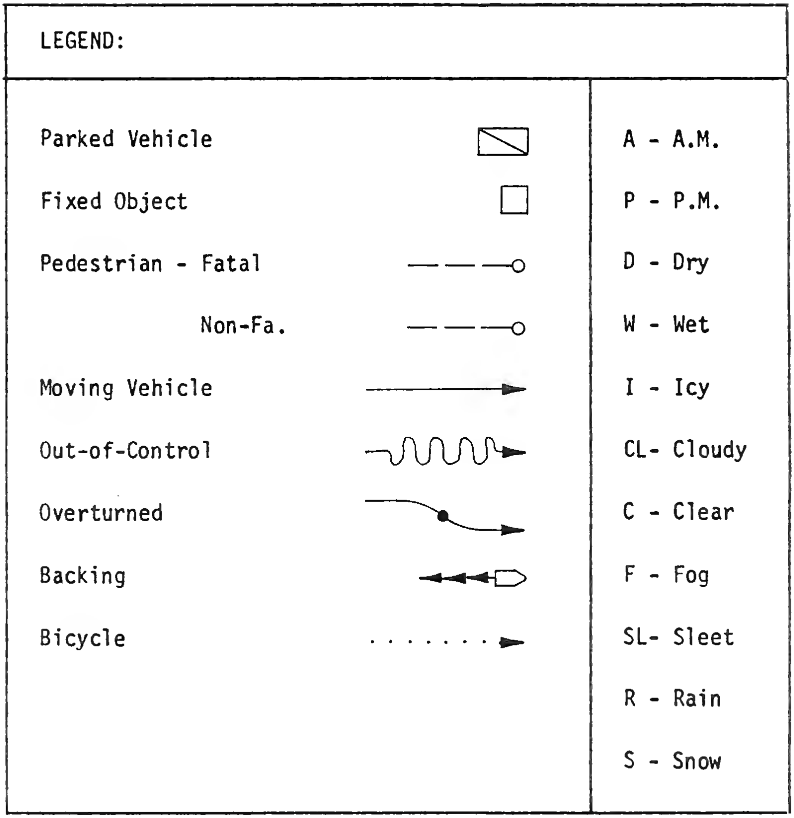


Figure A4. Legend for Collision Diagrams

COLLISION DIAGRAM and TABULAR SUMMARY

City____________________ Period: from____________ to____________

Location____

TYPE	TOTAL			
	PI	PD	FA	ALL
Right Angle				
Rear End				
Head On				
Side Swipe: Opp. Dir.				
Same Dir.				
Wrong Lane: Lt. Turn				
Rt. Turn				
Correct Lane Lt. Turn				
Rt. Turn				
Fixed Object				
Out-of-Control				
Pedestrian				
U-Turn				
Other				
TOTAL				

Date Compiled________________

Traffic Controls________________

____

Data Source________________

Analyst________________

Figure A5. Collision Diagram and Tabular Summary

Sample Form

SERVICE ROAD SURVEY

Form A - Businessperson

Location- Date-

Name and Address of Business-

1. How is the safety of your customers affected by your being located on a service road?

2. Comment on the hypothesis that the preservation of the traffic-carrying capability of the arterial street is essential to the continued success of your business.

3. What do you feel is the effect of being located on a service road on your potential volume of business?

4. Do you feel that the service road or the median has the greater effect on the number of your customers?

5. What changes would you suggest in the design and layout of this section of highway?

6. Estimate the number of trips generated by your business between the hours of 7:30 a.m. and 6:00 p.m.

7. Approximately how many square feet of floor space is devoted to your business?

8. How do you feel the service road has affected the value of land along it?

Figure A6. Service Road Survey: Form A--Businessperson

Sample Form

SERVICE ROAD SURVEY

Form B - Customer

Location- Date-

Name and Address of Business-

1. On the average, about how often do you make a trip to the service road area?

2. How do you feel the service road affects the safety of driving in this area? Explain.

3. Does the service road make any difference in your ability to move around during congested periods? Explain.

4. Do you find that the service road creates any significant inconvenience of accessibility to the roadside development? Explain.

5. Does the median or the service road cause the greater inconvenience in moving between the businesses and the highway? Why?

6. What changes would you suggest in the design and layout of this section of highway? (e.g., continous, both sides, etc.)

7. Would you like to see more service roads along Indiana highways?

Figure A7. Service Road Survey: Form B--Customer

APPENDIX B

Study Area Diagrams

1 - Service Stations

2 - Restaurants

3 - Stores and Shops

4 - Offices

5 - Small Industries

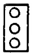
6 - Motels

7 - Miscellaneous

8 - Residences or Apartments

 - STOP sign

 - Other signs

 - Traffic signal

 - Mailbox

Figure B1. Land Use Coding Scheme and Traffic Control Notation

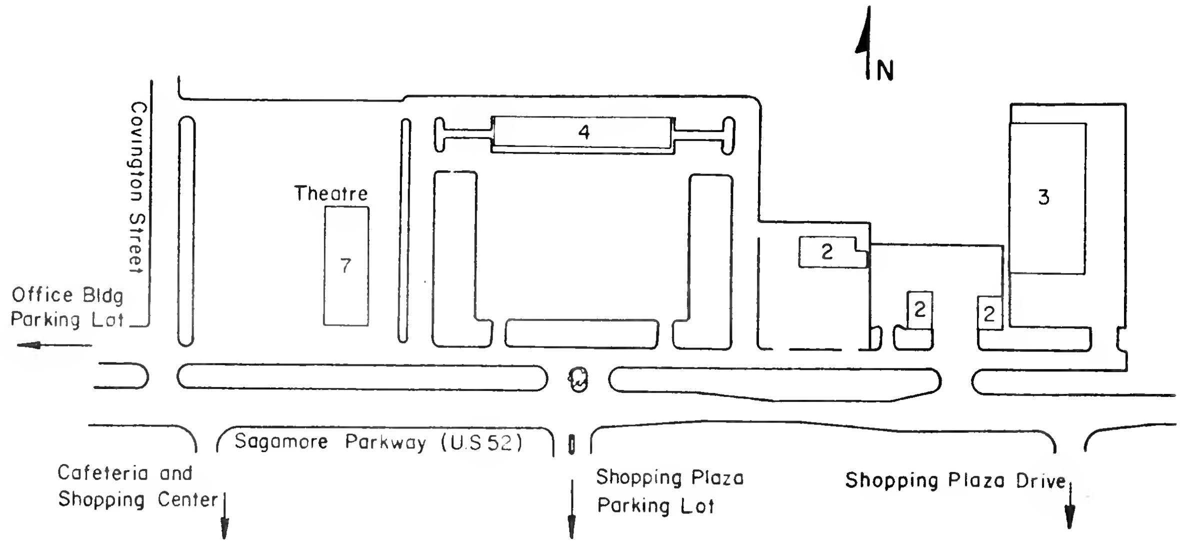


Figure . . Service Road Study Area, 300- W. Sagamore Pkwy. (US 52 Bypass), West Lafayette

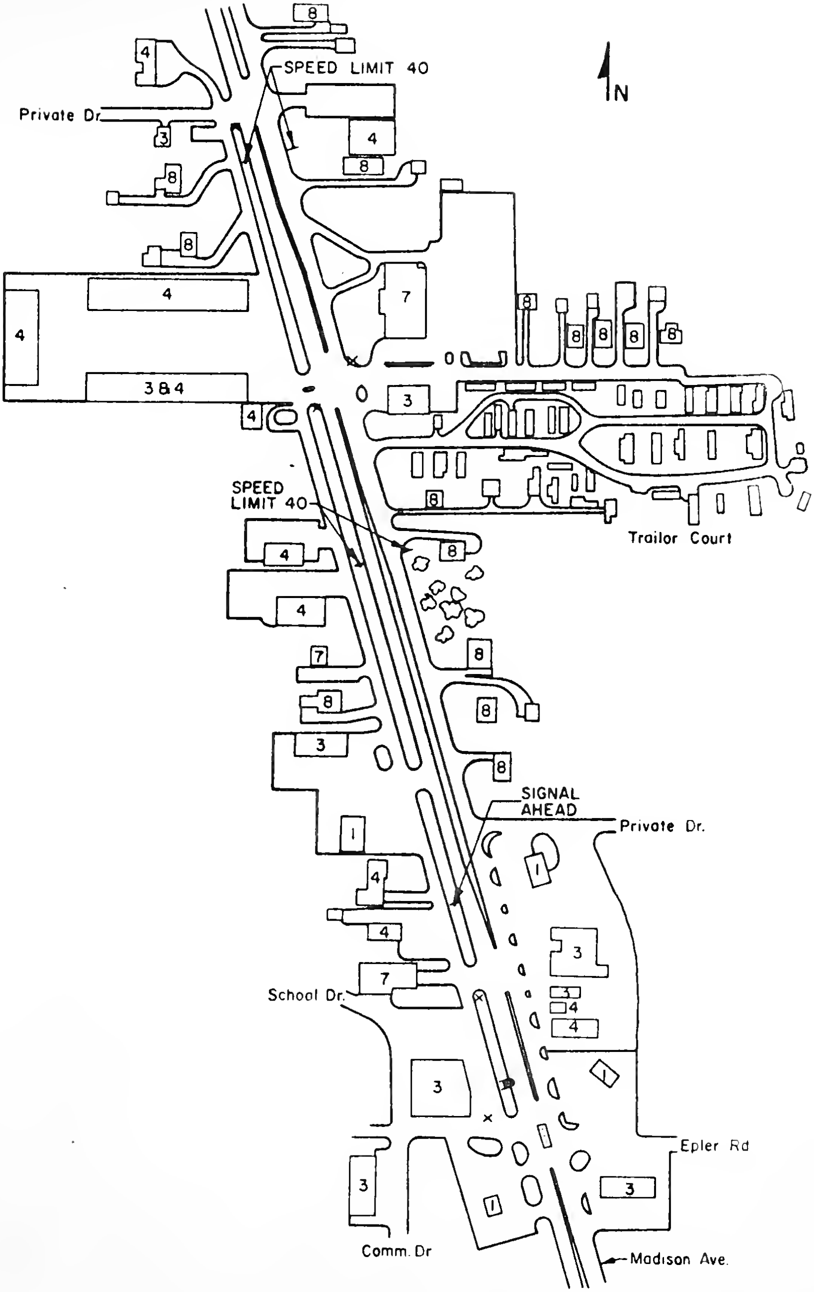


Figure B3. Service Road Study Area, 5050-5500 S. Madison Ave. (SR 431), Indianapolis

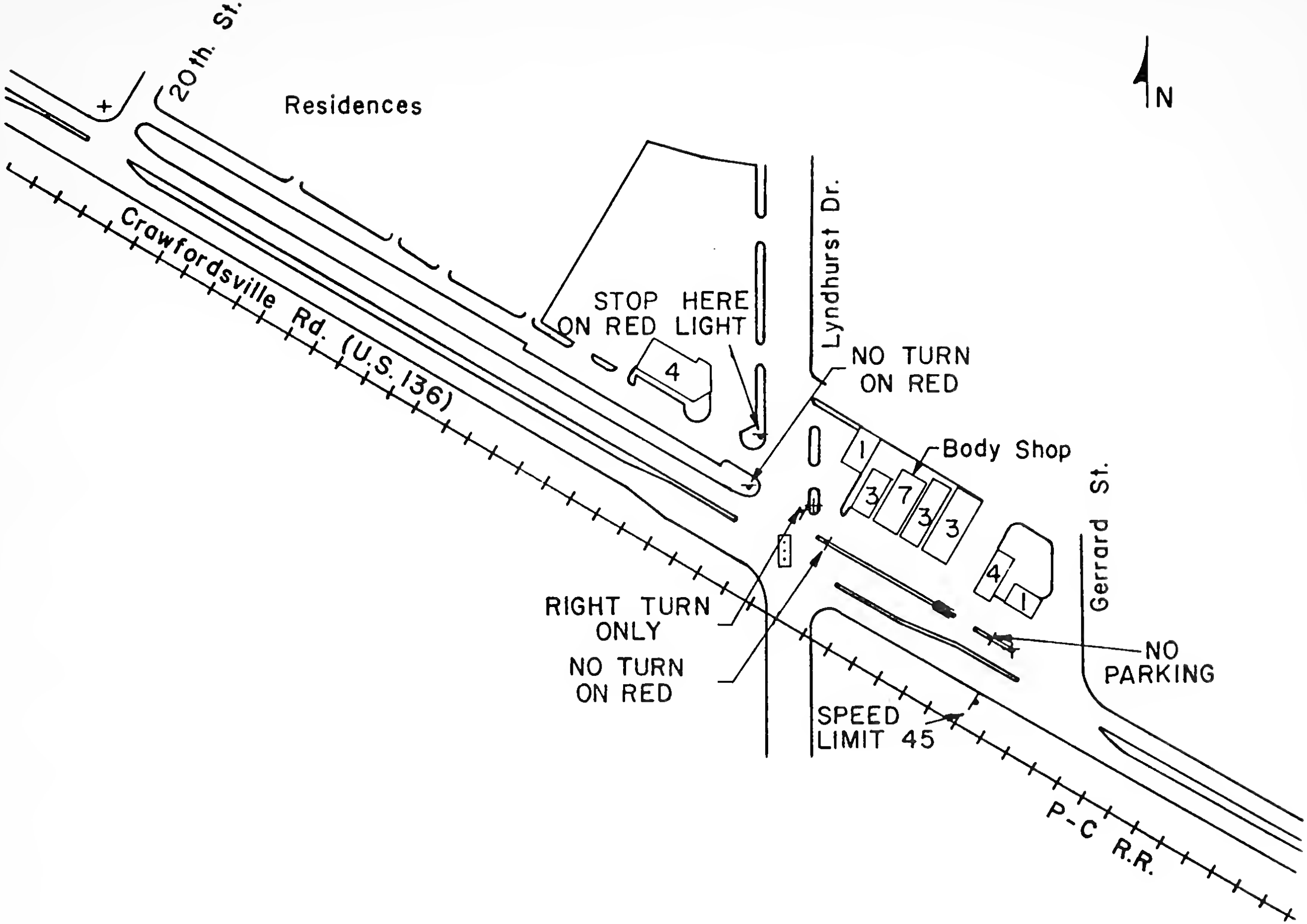


Figure B4. Service Road Study Area, 5220-5350 W. Crawfordsville Road (US 136), Speedway

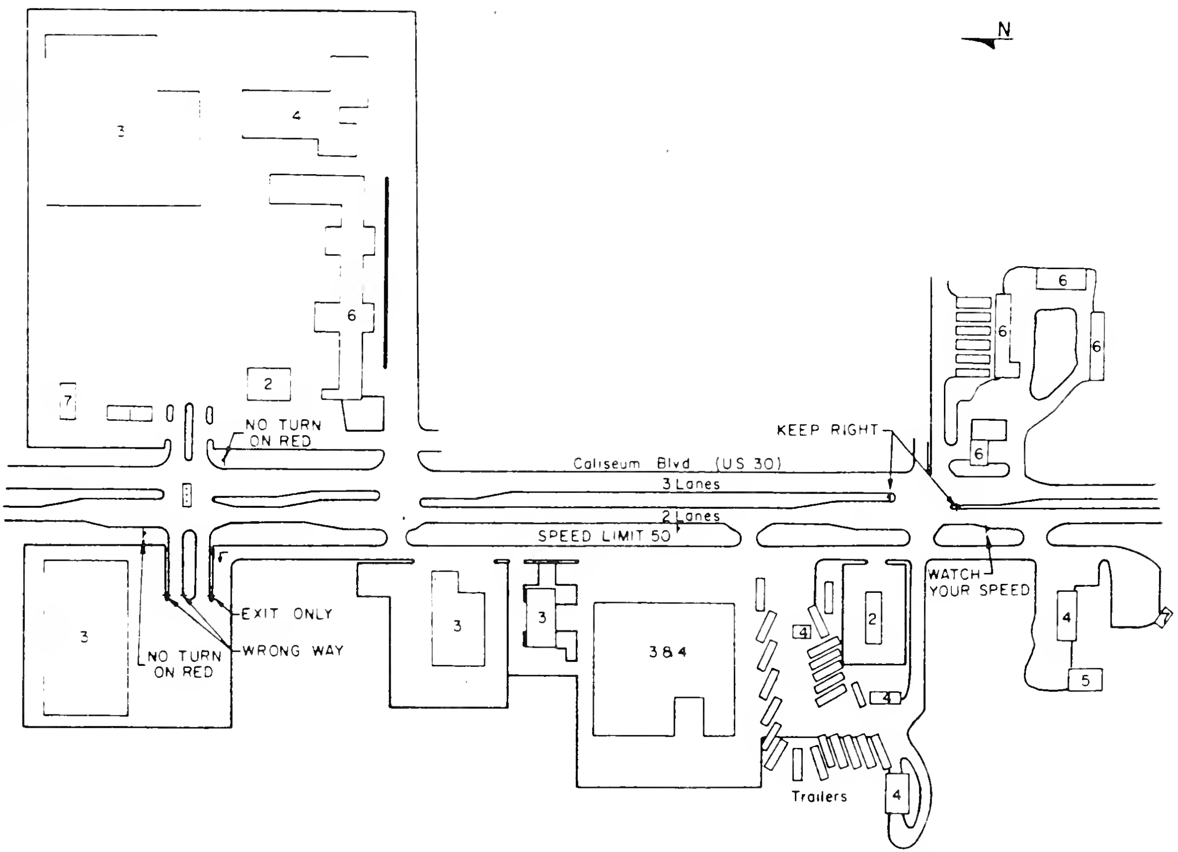


Figure B5. Service Road Study Area, 707-1133 N. Coliseum Blvd. (US 30 Bypass), Fort Wayne

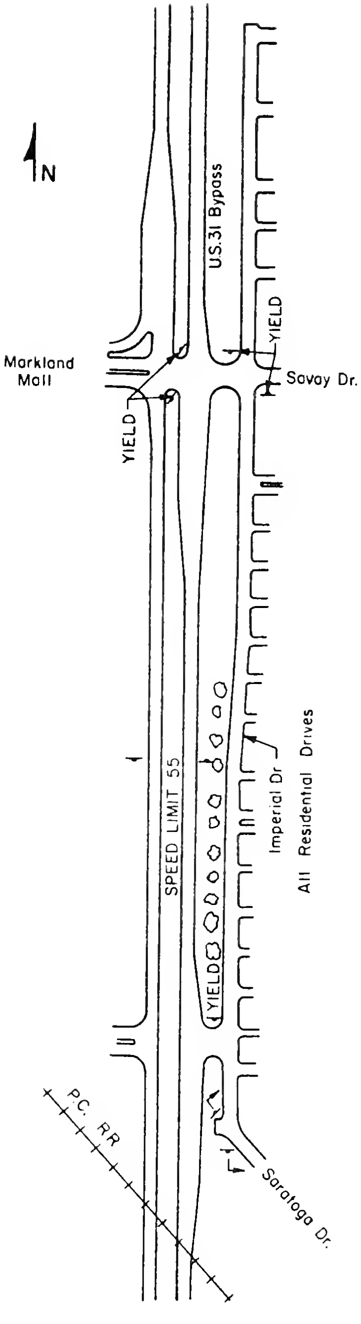


Figure B6. Service Road Study Area, 1220-1520 S. US 31 Bypass, Kokomo

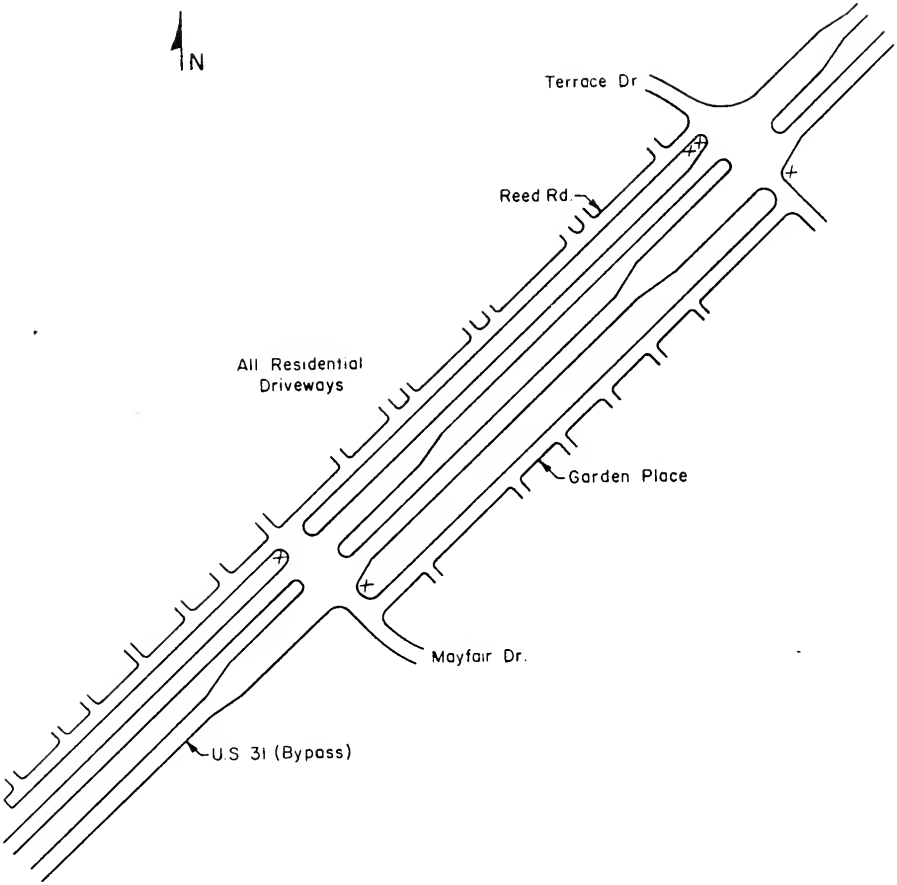


Figure B7. Service Road Study Area, 3000-3120 S. US 31 Bypass, Kokomo

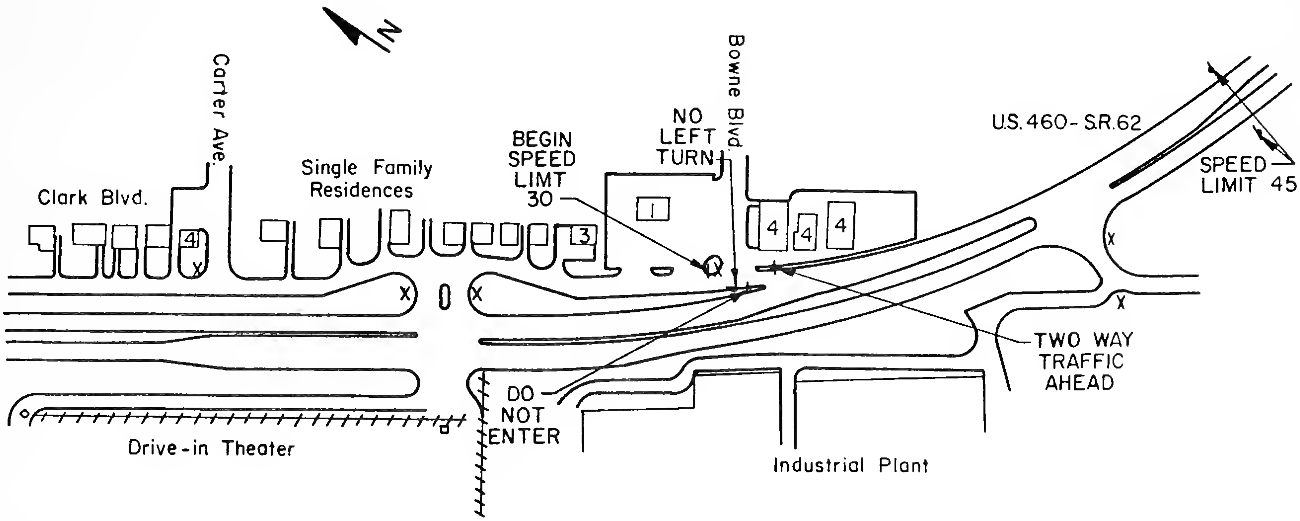


Figure B8. Service Road Study Area, 500-630 N. US 460, Clarksville

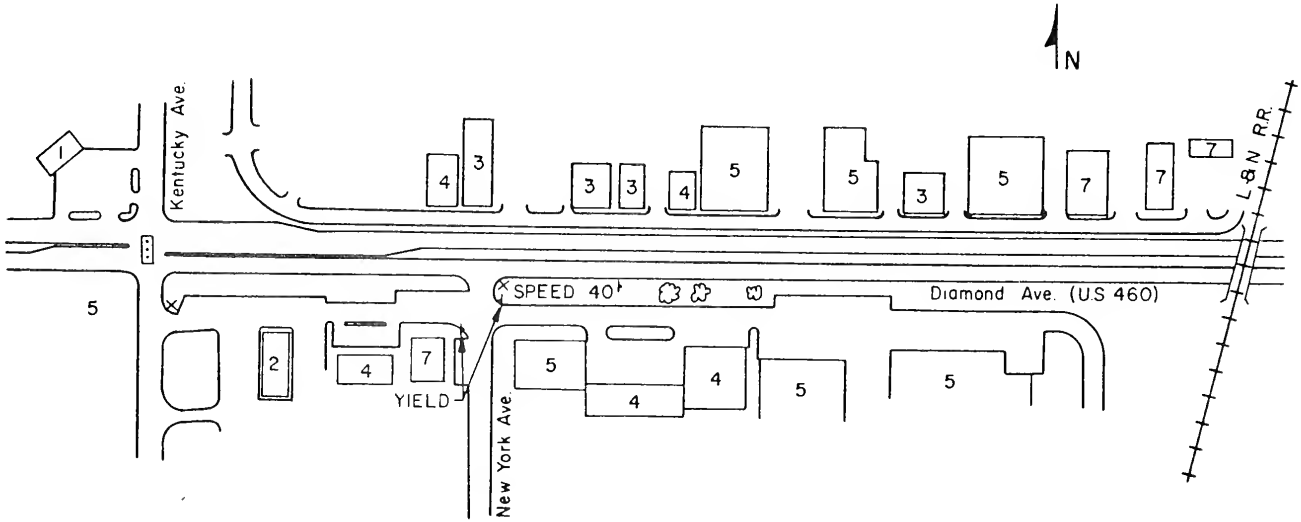


Figure B9. Service Road Study Area, 1000-1200 E. Diamond Ave. (US 460), Evansville

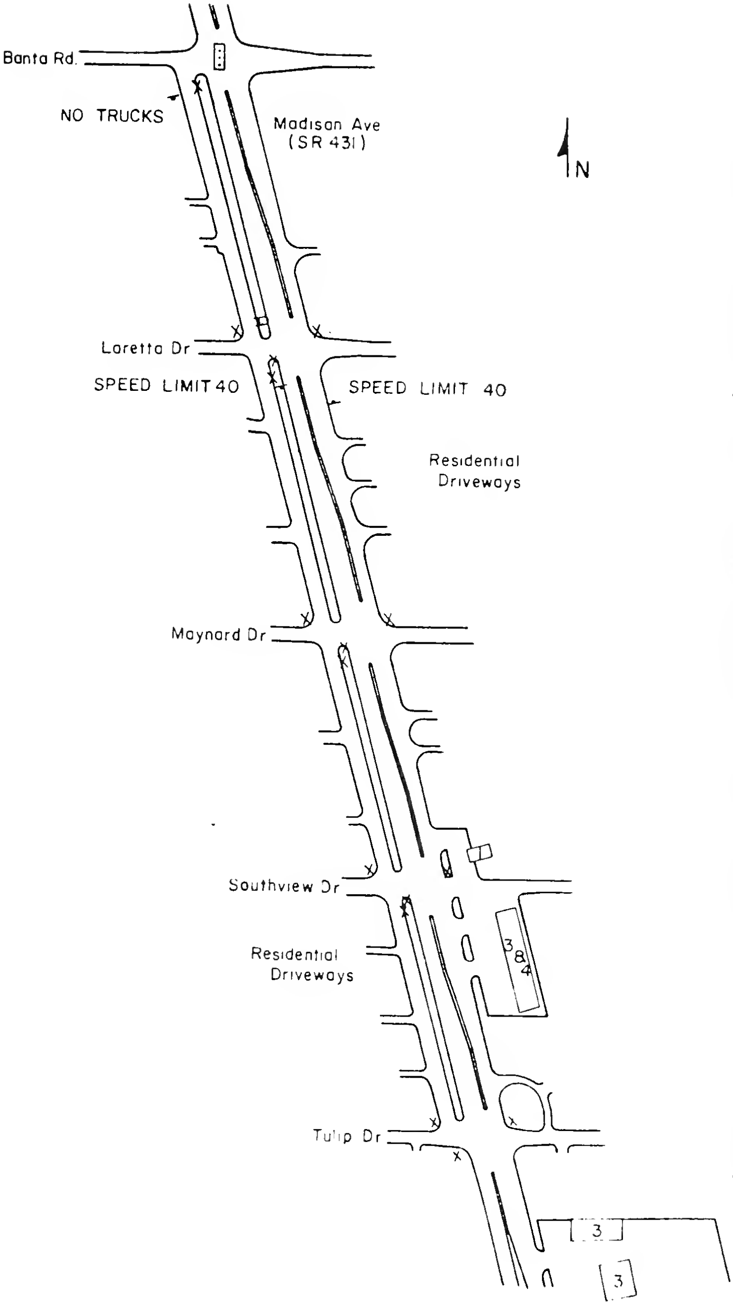


Figure B10. Service Road Study Area, 6500-6840 S. Madison Ave. (SR 431), Indianapolis

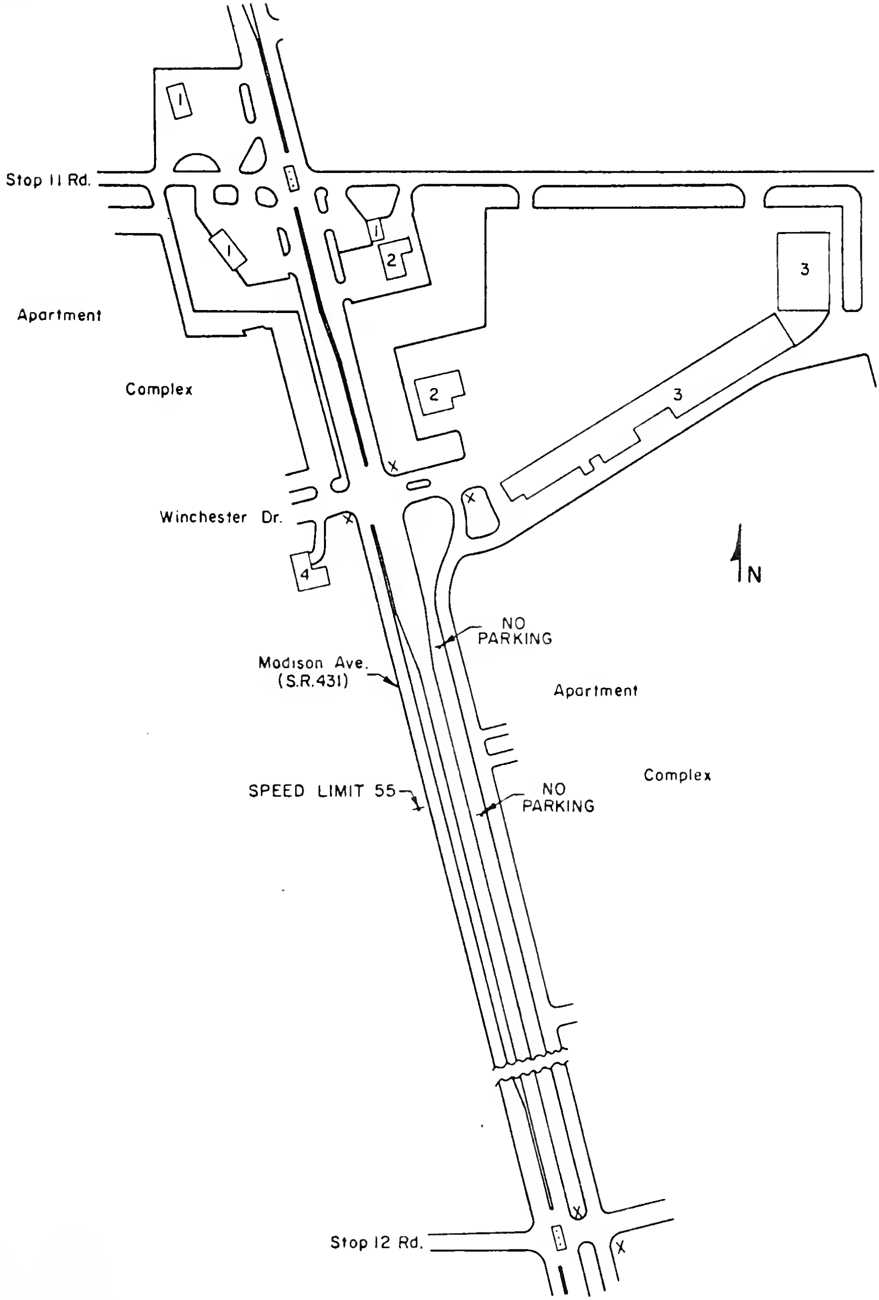


Figure B11. Service Road Study Area, 8100 S. Madison Ave. (SR 431), Indianapolis

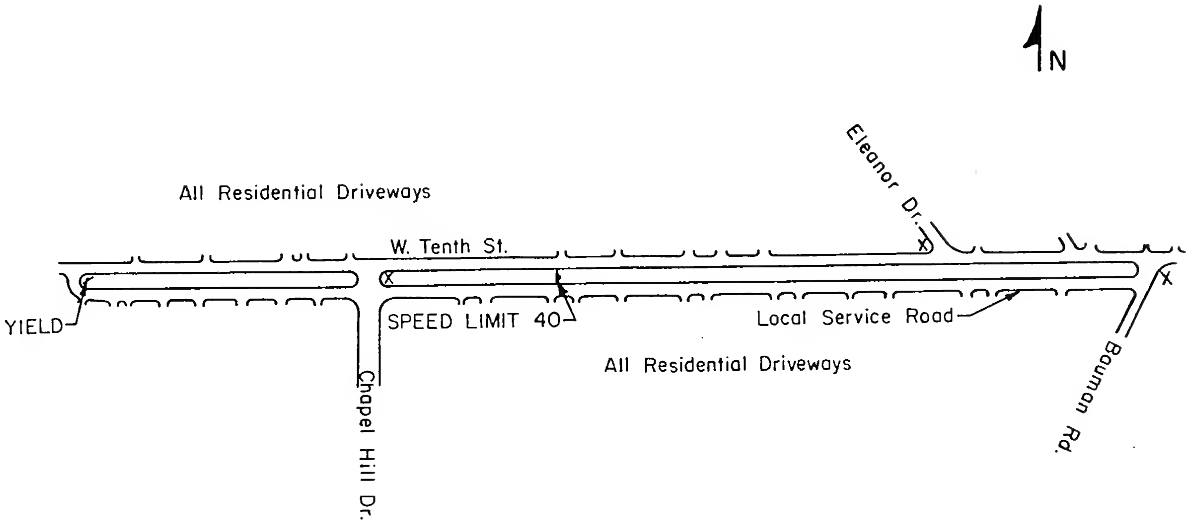


Figure B12. Service Road Study Area, 6707-7107 W. Tenth St., Indianapolis

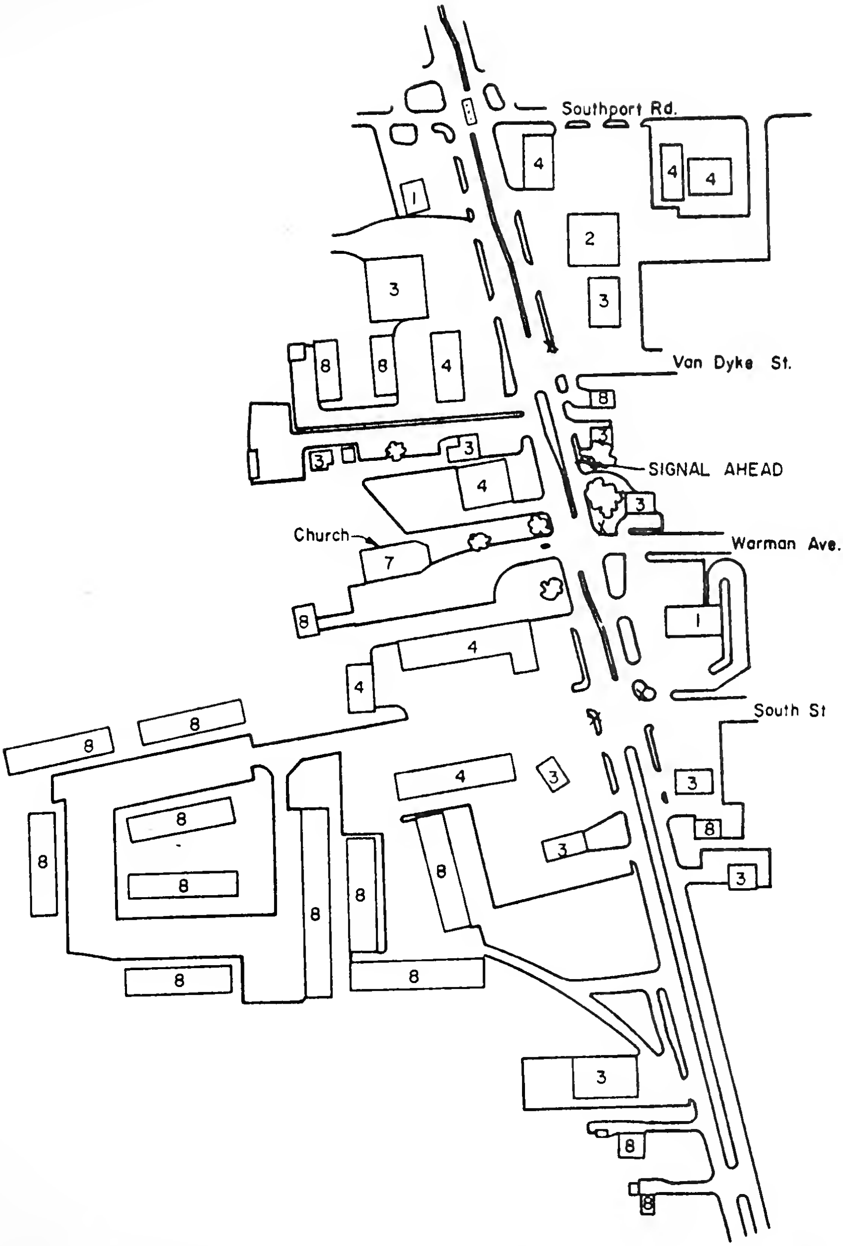


Figure B13. Direct Access Study Area, 7020-7440 S. Madison Ave. (SR 431), Indianapolis

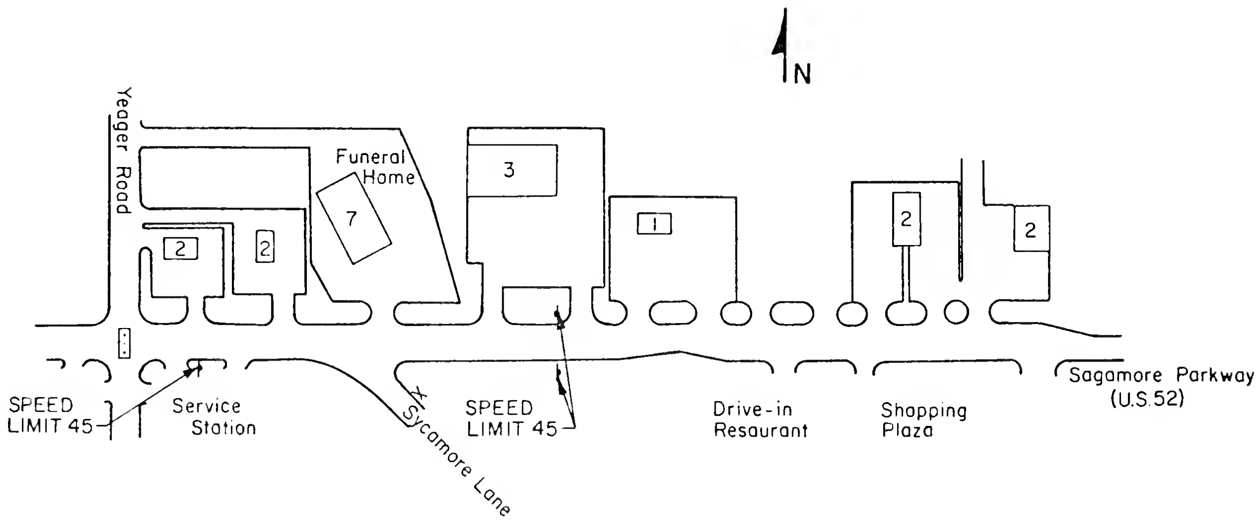
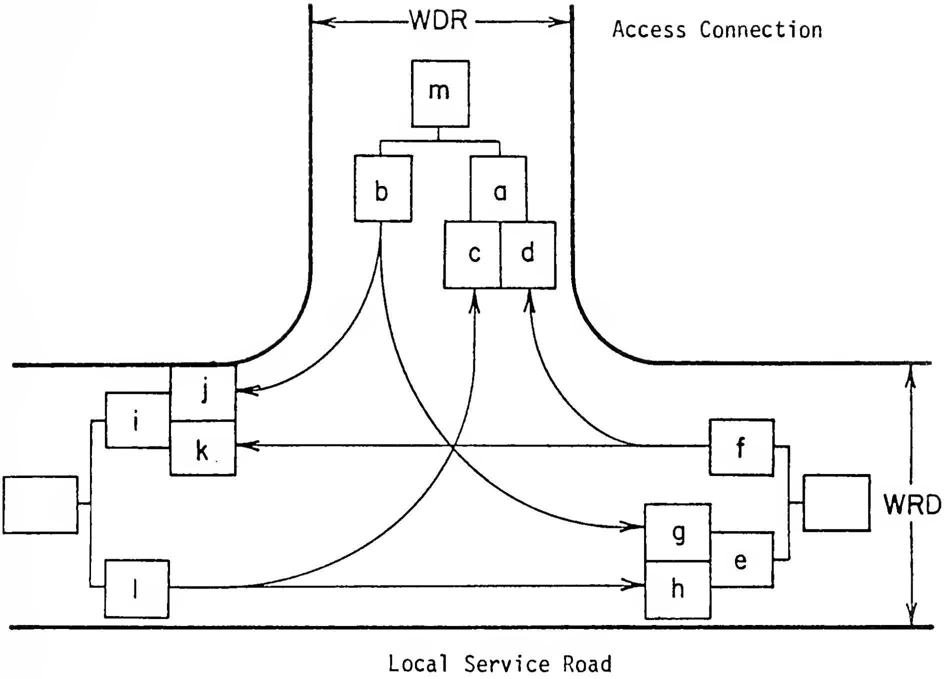


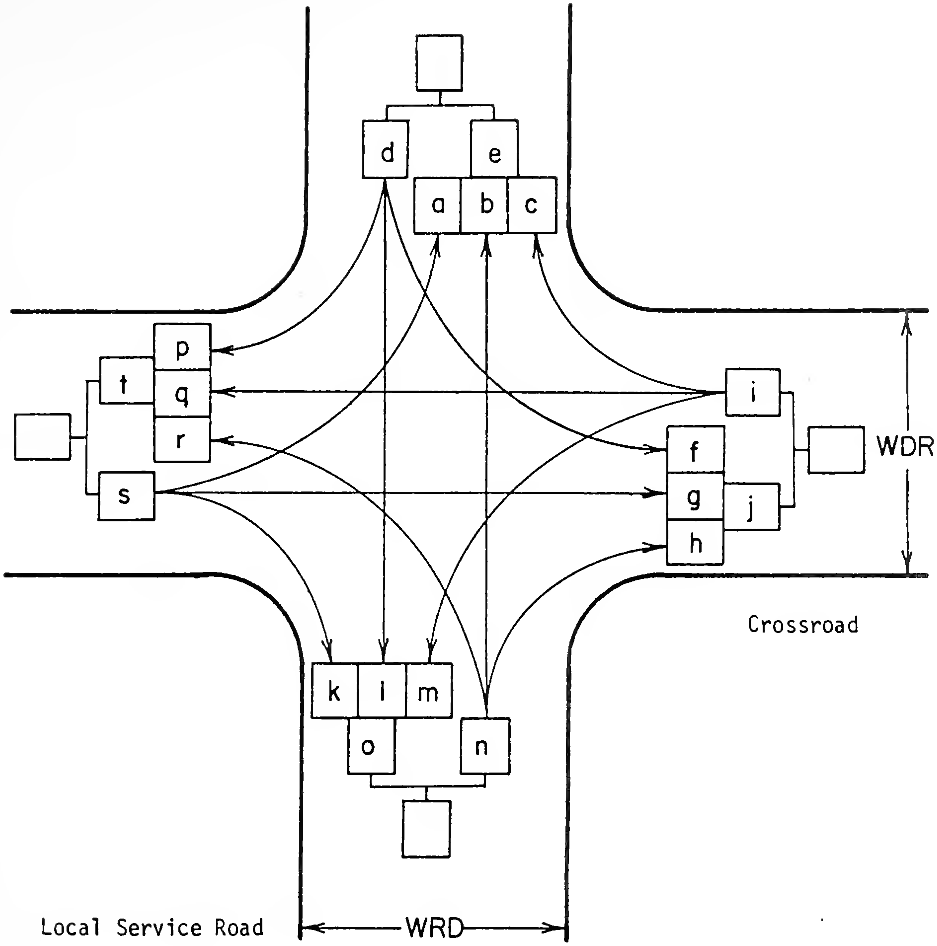
Figure B14. Direct Access Study Area, 1070-1200 W. Sagamore Pkwy. (US 52 Bypass), West Lafayette

APPENDIX C
Calculation of Variables



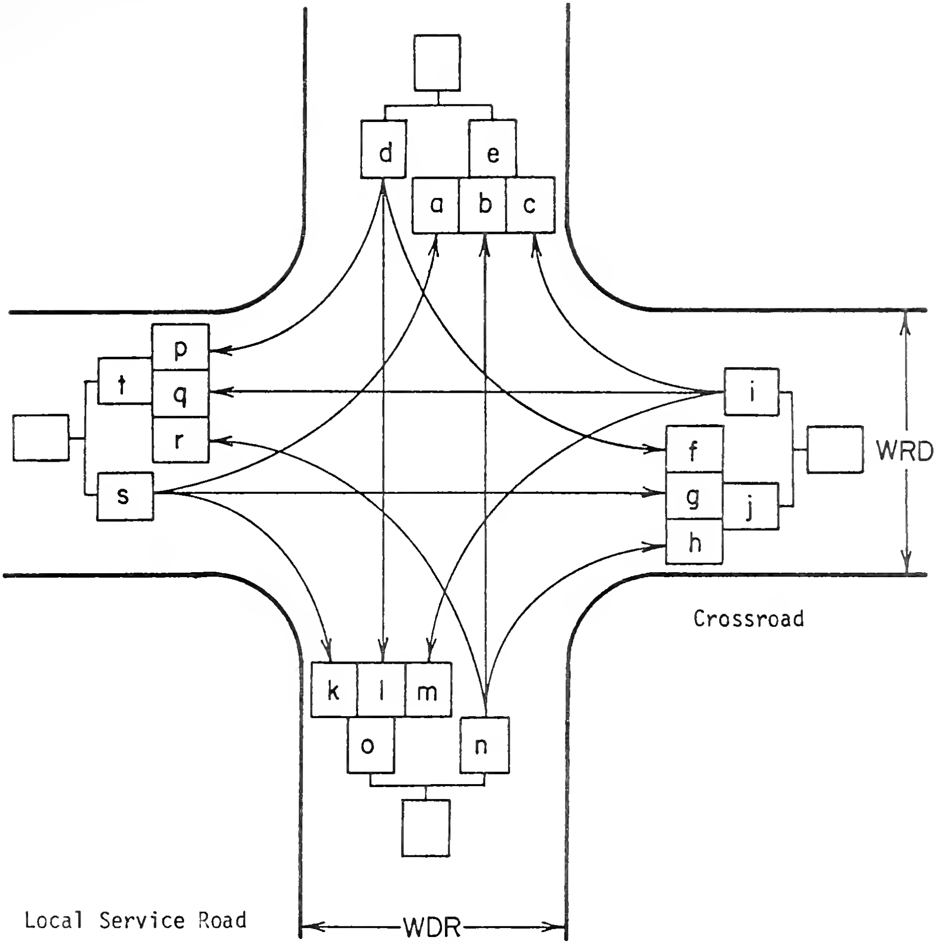
HVS = f+1	TPNL = g/h
CVS = m	TVN = b
SVS = m/(f+1)	TVXR = d
VTI = b+f+1	TPXR = d/f
TVNR = j	TVXL = c
TPNR = j/k	TPXL = c/1
TVNL = g	TVX = a

Figure C1. Calculation of Variables for Type A LSR Intersections, Service Road Approaches



HVS = d+n
CVS = i+s
SVS = (i+s)/(d+n)
VTI = (d+n)+(i+s)
TVNR = k+c
TPNR = (k+c)/[(l+m)+(a+b)]
TVNL = m+a
TPNL = (m+a)/[(k+l)+(b+c)]
TVN = (k+c)+(m+a)
TVXR = h+p
TPXR = (h+p)/(n+d)
TVXL = f+r
TPXL = (f+r)/(n+d)
TVX = (h+p)+(f+r)

Figure C2. Calculation of Variables for Type B LSR Intersections, Service Road Approaches



HVS = i+s

CVS = d+n

SVS = (d+n)/(i+s)

VTI = (d+n)+(i+s)

TVNR = h+p

TPNR = (h+p)/[(f+g)+(q+r)]

TVNL = f+r

TPNL = (f+r)/[(g+h)+(p+q)]

TVN = (h+p)+(f+r)

TVXR = k+c

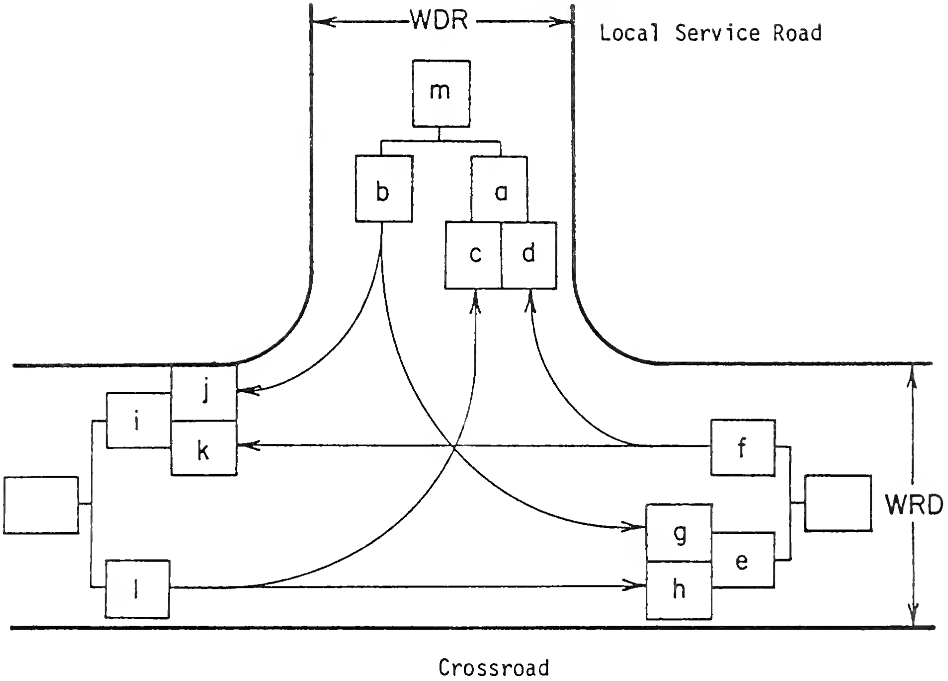
TPXR = (k+c)/(i+s)

TVXL = a+m

TPXL = (a+m)/(i+s)

TVX = (k+c)+(a+m)

Figure C3. Calculation of Variables for Type B LSR Intersections, Crossroad Approaches



HVS = f+l

CVS = m

SVS = m/(f+l)

VTI = b+f+l

TVNR = j

TPNR = j/k

TVNL = g

TPNL = g/h

TVN = b

TVXR = d

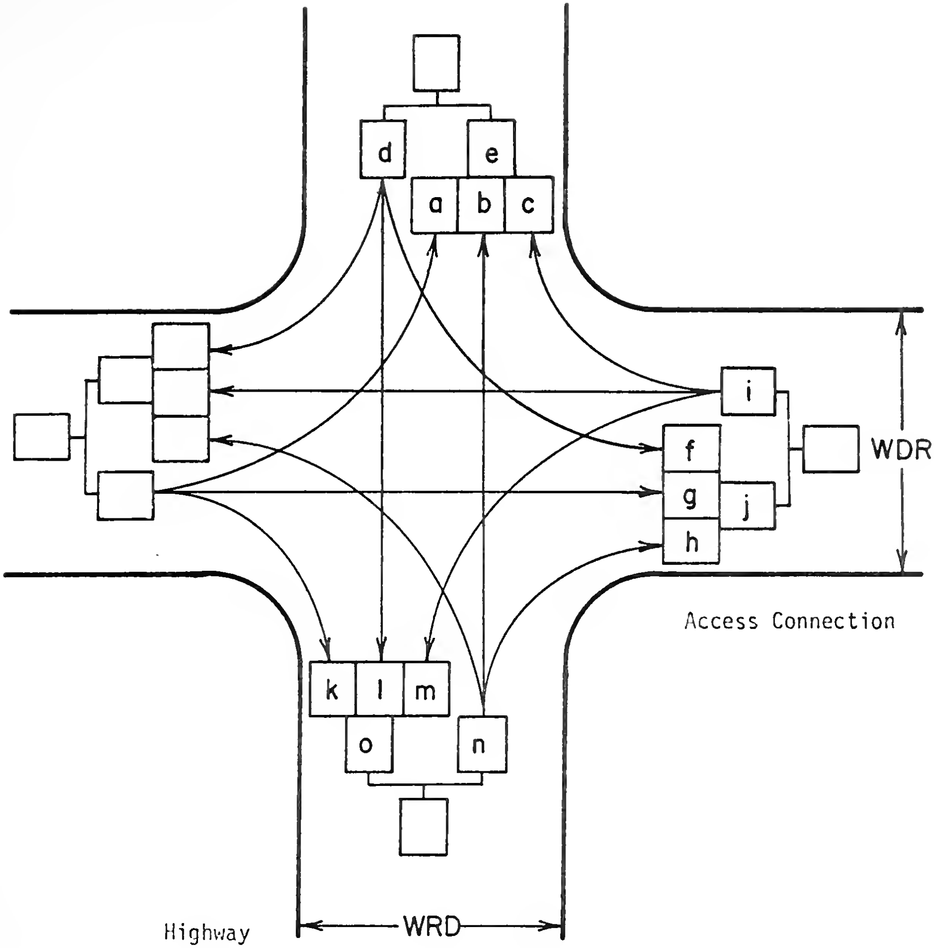
TPXR = d/f

TVXL = c

TPXL = c/l

TVX = a

Figure C4. Calculation of Variables for Type D LSR Intersections, Crossroad Approaches



HVS = d+n

CVS = i+j

SVS = (i+j)/(d+n)

VTI = (d+n)+(i+j)

TVNR = c

TPNR = c/(a+b)

TVNL = m

TPNL = m/(k+l)

TVN = c+m

TVXR = h

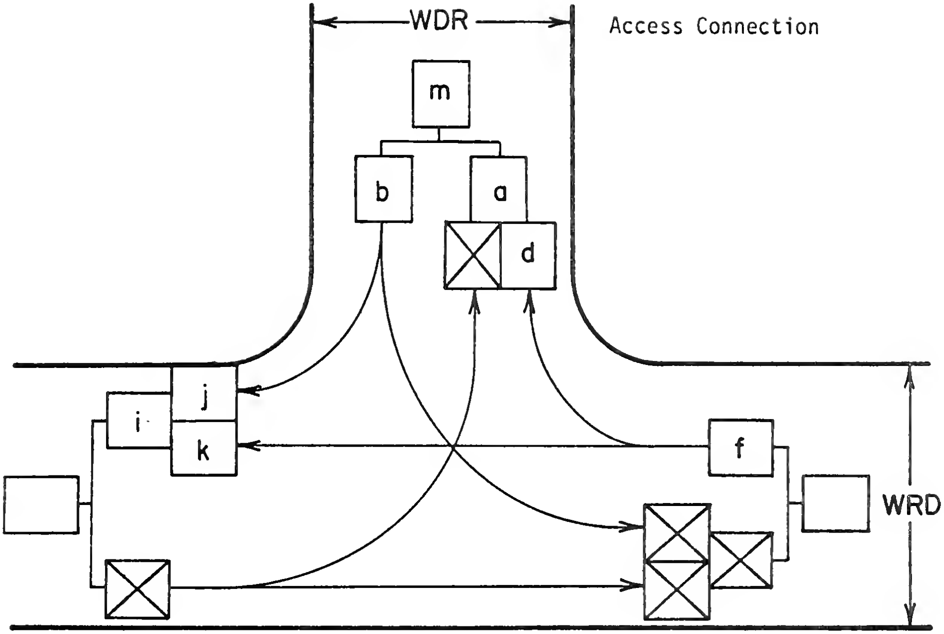
TPXR = h/n

TVXL = f

TPXL = f/d

TVX = f+h .

Figure C5. Calculation of Variables for Type E and H Highway Intersections, Highway Approaches



Highway - One Direction

HVS = f	TPNR = j/k
CVS = m	TVNR = b
SVS = m/f	TPXR = d/f
VTI = b+f	TVXR = d

Figure C6. Calculation of Variables for Type G Highway Intersections, Highway Approach

COVER DESIGN BY ALDO GIORGINI